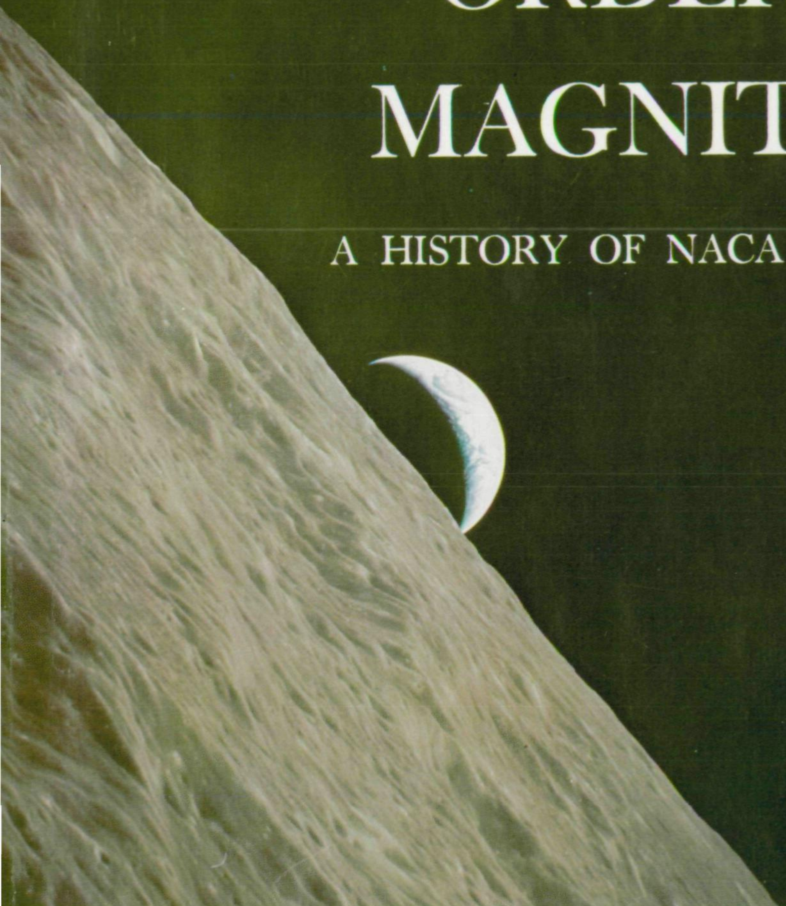
ORDERS OF MAGNITUDE

A HISTORY OF NACA AND NASA, 1915-1976



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A HISTORY OF NACA AND NASA,

1915–1976

By Frank W. Anderson, Jr.

The NASA History Series
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ORDERS OF MAGNITUDE

A History of NACA and NASA, 1915-1976

THE AUTHOR

Frank W. Anderson, Jr., Publications Manager in the NASA History Office, has overseen the production of NASA historical publications since 1961. Born in Birmingham, Alabama, he received his B.A. degree in English from Birmingham-Southern College and his M.A. and Ph.D. degrees from the University of North Carolina, where he taught English. He served in the Army Air Force during World War II and in the Air Force during the Korean War. From 1954 to 1961 he was managing editor of the *Air University Review,* following three years as assistant and then associate editor. He also has been a historian at the Air University and an editorial consultant for the Air War College.

The editor of *Great Flying Stories* (Dell, 1950), he was a consulting editor for *Webster's Third New International Dictionary* and the author of "Satellites, Space Probes, and Manned Space Flights" and "Major NASA Launches" in NASA's annual *Astronautics and Aeronautics* chronology volumes for 1962 through 1967.

Foreword

A number of scientists and science writers have assessed our twentieth century efforts in aeronautics and space from a hypothetical vantage point a few hundred years hence. All have maintained that our methods, machines, and achievements will then seem to have been pitifully limited and primitive. We can, of course, play the same game with history. To someone viewing the world from the vantage point of a jet airliner, the Montgolfier balloon of less than 200 years ago or the man flying prone and exposed on the skeleton of a Wright Flyer some 70 years ago can also seem primitive. Yet the learning curve that culminated in the creation of that airliner had its beginnings in those courageous early ventures.

To those of us who have spent a large part of our lives working in aeronautics and the space program, the perspective is different and yet similar. When you are working on a project, beseiged by deadlines, progress often seems agonizingly slow, answers tantalizingly elusive. Yet when, in the midst of the exciting development of the Space Shuttle, you look back to a corresponding point in the Apollo program a mere ten years ago, the sense of rapid progress is very real.

The approach of our national bicentennial is cause for such reflections about many aspects of our national life. In this small volume NASA offers an overview of the Federal government's role in contributing, by research and development, to the advancement of aeronautics and of space exploration. Though these pages cover less than a third of our 200-year history as a nation, they trace the flight of man from a wobbly few hundred feet above the Earth's surface to confident walks and rides on the surface of the Moon. And a machine made by man even now nears the edge of our solar system and will proceed into the vastness of interstellar space.

Much will be said during our bicentennial celebration about the role of the venturesome spirit of man in the conquest of the American frontier. Science and technology have been worthy servants of that

spirit. The railroad and the electric telegraph were key elements in our westward expansion. But we might do well to remember that the standard gauge of the track of the American railroad was copied from coal-hauling wagons in northern England. And the dots and dashes of the Morse code which the telegraph flashed across the continent had precedent in the long and short flashes of light with which Napoleon's semaphore stations communicated across Europe. Which is to say that technological change, like all change, tends to carry with it much of the past.

In this century the American spirit has responded vigorously to the frontiers of air and space. Science and technology have responded with enlarged understanding and better vehicles. We begin our third hundred years as a nation with a space frontier of endless challenge. An unexcelled team of government, industry, and university facilities and people stands ready to provide more and more effective equipment for the venture.

GEORGE M. LOW
Deputy Administrator
National Aeronautics and Space Administration

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Preface

For some years the NASA History Office has been embarrassed by a thin but steady stream of requests for copies of a brief history of NASA. Again and again we had to say that none existed. There had been one once, back in 1965, when Eugene M. Emme, NASA Historian, wrote a *Historical Sketch of NASA* (EP–29). But it had been out of print for several years and by now was outdated enough to discourage a reprint. The project of a new short history kept nagging at our collective conscience, but we were busy with other things. It was not hard to convince ourselves that we just couldn't stretch our staff resources that much.

Then last year that persuasive imperative, necessity, took a hand. The American Public Works Association, armed with the blessing of a joint congressional resolution, was preparing a bicentennial volume of the history of 200 years of public works in the United States. Association officers asked the NASA Administrator, James C. Fletcher, to have a chapter prepared on the aeronautics and space programs. Dr. Fletcher agreed; the project was assigned to our office. So now it would be done; the only question was whether someone in the office would do it or whether we would contract for a manuscript. Mindful of our long-felt need for a similar manuscript, I volunteered. The bicentennial volume got its chapter and here, revised and somewhat enlarged, is the NASA version.

Because of the purpose for which it was originally written, it contains no reference notes and only a generalized bibliography. So I cannot blame the sources for errors or deficiences; they are of my own cobbling.

June 1975 F.W.A.

I

Rise of Aeronautics

In 1913 the clouds of war were gathering over Europe—and casting their shadows on America. The European powers were racing to arm themselves against each other—not only with conventional land and sea armaments, but also with the new weapon of the twentieth century—the airplane. In their race they overcame the U.S. lead established by the Wright brothers and left this country in a technological backwash. Particularly disturbing to American observers was our primitive and unorganized aeronautical establishment—a frail shadow of the research facilities and government subsidized industries arising in Europe.

Most active among the small group of concerned men in the United States was the Secretary of the Smithsonian Institution, Charles D. Wolcott. Convinced that the situation called for Federal sponsorship of an aviation organization, he worked hard selling the idea both inside and outside the Government. After several false starts, he succeeded. On 3 March 1915, President Woodrow Wilson signed into law a Navy appropriations bill with a rider establishing an independent Advisory Committee for Aeronautics. The munificent sum of $5000 was appropriated for the Committee's first year's operations.

The new Committee was unique in organizational structure, though in years to come it was to serve as a model for several others. Twelve presidentially appointed members, serving without pay, drawn from the military and scientific sides of government and from the scientific community at large, were charged "to supervise and direct the scientific study of the problems of flight, with a view to their practical solution," and to "direct and conduct research and experiments in aeronautics."

First among the tasks of the Committee was to find the dimensions of the problem. They set out to survey the state of aeronautics in the United States. If their purpose had been to justify their existence, they

would have found the results amply rewarding. Aviation was generally regarded as a dare-devil sport practiced by a handful of wealthy young men. Aeronautical research was virtually nonexistent. Only two American universities even offered courses in aeronautical engineering. Research facilities such as wind tunnels were pitifully few in number and unsystematized in use. The aviation "industry" was a scattered collection of small handicraft shops. The military services had bought only a few dozen airplanes in the brief history of aviation, and nearly all of them were fatally obsolete by current European standards. And finally, none of the work in aeronautics within the government (located in the Weather Bureau, the Bureau of Standards, and the military services) and in the civil sector was coordinated. Clearly a Federal laboratory for aeronautical research was urgently needed.

Army, Navy, and the Committee agreed to establish a joint research center. Since the War Department had funds for acquiring real estate, it bought a tract of land on the Back River near Hampton, Virginia. The intent was to colocate the aeronautical research facilities of the two military services and the Committee. Realities of war intervened, however; the War Department left its research at McCook Field in Dayton, Ohio (later Wright Field, now Wright-Patterson Air Force Base); the Navy located its facility in Norfolk, Virginia. The National Advisory Committee for Aeronautics—already acronymed NACA—went ahead with construction. Even so it was too late for the laboratory to begin operations in time to assist the war effort. Not until 11 June 1920 was the three-building complex—one of them a wind tunnel with a 1.5-meter test section—formally dedicated as the Langley Memorial Aeronautical Laboratory (named for Samuel P. Langley, aeronautical pioneer).

FROM WAR TO WAR

During the 1920s the new laboratory took form and substance. The needed theoretical base for scientific study of aeronautics was imported from Europe, and NACA staffed the laboratory slowly and carefully. A conscious decision was made to concentrate on the systematic study of aerodynamics—the interactions between the three-dimensional air-space and the shape and characteristics of a body moving through it—as the most needed of the many areas of research in aeronautics. Additional research facilities were built, carefully tailored to that purpose. Most of the credit for this hard focus and foresight should go to

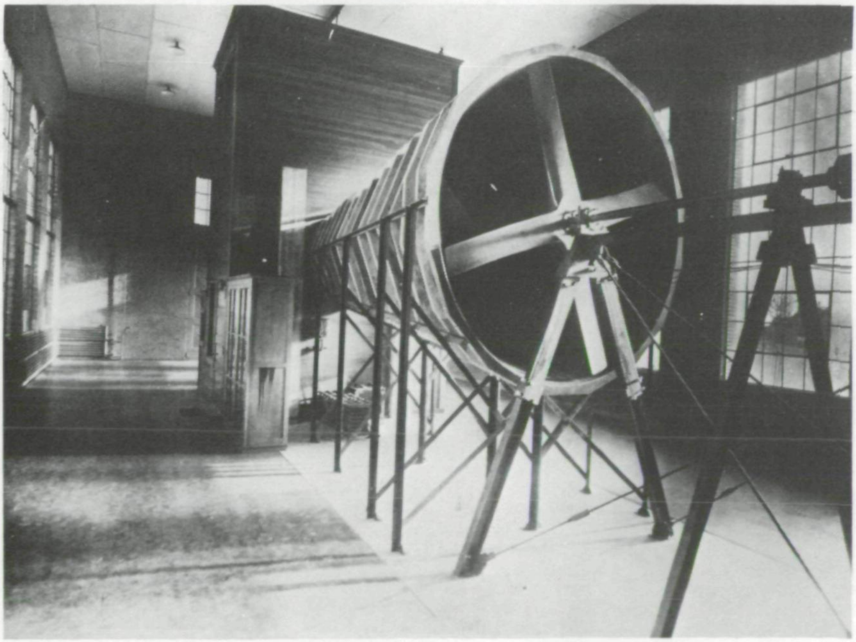
two dedicated members of the Committee—Joseph S. Ames of Johns Hopkins University and Jerome C. Hunsaker of the Navy's Bureau of Aeronautics.

By the end of the decade the fledgling NACA had achieved impressive results, recognized at home and abroad. In 1929 a distinguished British engineer declared: "The only people so far who have been able to get at something like accurate results from wind tunnel experiments are the workers at the experimental station at Langley Field." In the same year a British engineering journal went further:

> They [the Langley group] were the first to establish, and indeed to visualize, a variable-density tunnel; they have led again with the construction of the twenty-foot propeller research tunnel; and steps are now being taken to provide a "full-scale" tunnel in which complete aeroplanes up to thirty-five-foot span can be tested. The present-day American position in all branches of aeronautical knowledge can, without doubt, be attributed mainly to this far-seeing policy and expenditure on up-to-date laboratory equipment.

Among the most important results of Langley's aerodynamic research with the new facilities were: the NACA cowling (1928), whose streamlined shape increased aircraft speed; systematic studies of aero-

Langley Laboratory's first wind tunnel, finished in 1920.

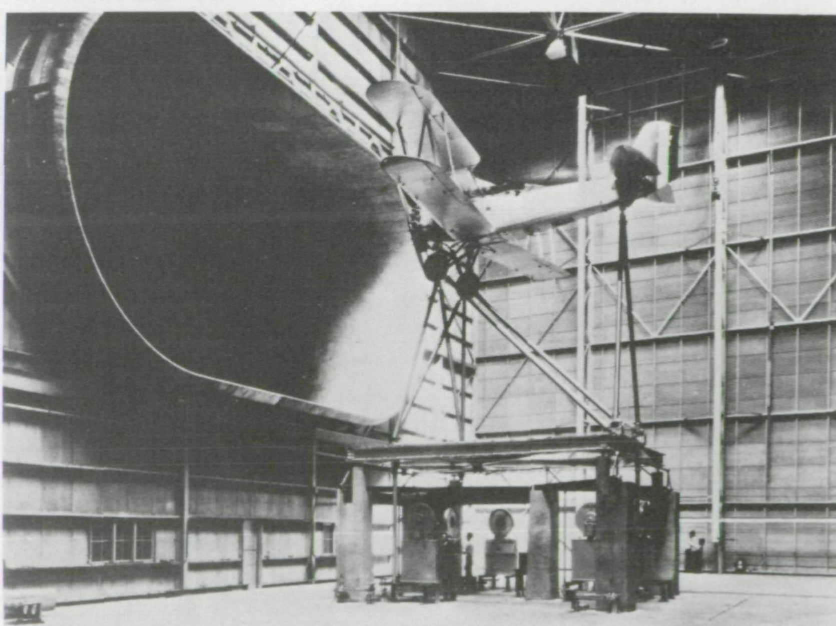


dynamic drag which put firm numbers on the penalties to performance from such design practices as locating engine nacelles apart from the wings or fuselage instead of merging them into the structure (1930); and the penalties of using fixed, exposed landing gear instead of retracting the wheels into the structure (1929).

In Washington the 1920s saw the main Committee and its technical subcommittees become established as the most knowledgeable source of advice on aeronautics in the country and the clearinghouse for exchange of information. Much of this sure rise to ascendency in U.S. aeronautical research derived from the selection of George W. Lewis, professor of mechanical engineering at Swarthmore College, as Director of Aeronautical Research. Joining NACA in 1919, Dr. Lewis for the next 26 years planned the research program, apportioned the money, and hired and trained the people in NACA.

The great depression that swept the United States in 1929 proved a boon to NACA in at least two senses: First, additional research facilities could be constructed at low depression prices with money already appropriated (mostly pump-priming money from the Public Works Administration); second, government salaries and the up-to-date re-

The full-scale wind tunnel at Langley, completed in 1931.



search facilities suddenly were very attractive to promising young engineers. Thus, in 1931, the 9-meter by 18-meter "full scale" wind tunnel, then the largest in the world, was completed at a cost of $900 000; the 610-meter-long towing tunnel was also finished that year. More wind tunnels were added in the mid-30s, and from a total staff of 181 people in 1930, NACA grew to 523 by 1939. Painstakingly and systematically the researchers charted out the family of NACA wing shapes that would shortly lift military and civil aircraft all over the world. As aircraft speeds rose, new aerodynamic problems had to be solved. Stalls and spins, treacherous problems that had caused a fourth of all aircraft accidents, were explored, understood, and largely countered.

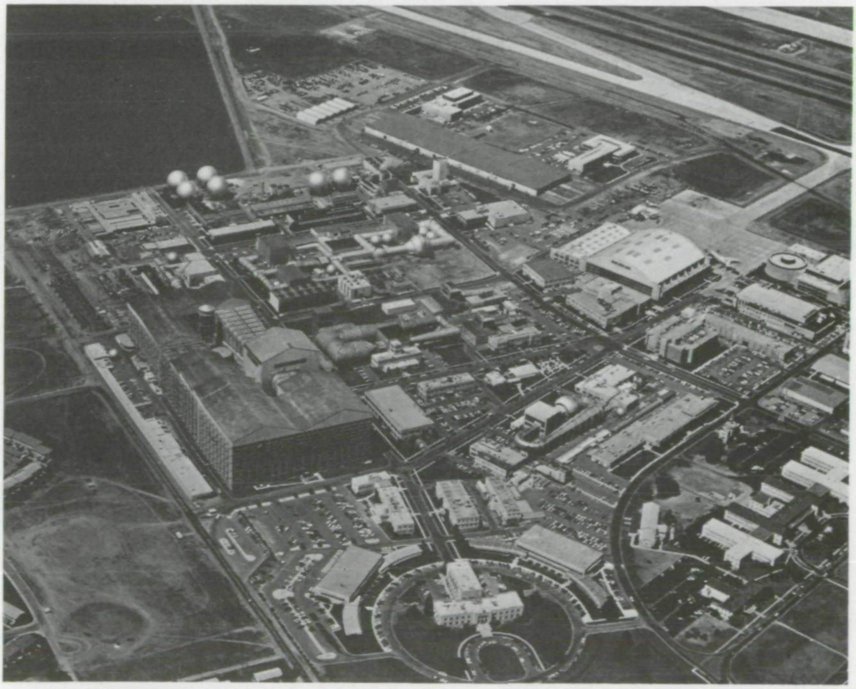
By 1936 NACA officials became aware of two interconnected problems looming on the horizon: (1) European nations were again rapidly building new research facilities; (2) room for growth was limited at Langley. Once more American leadership in aeronautics was challenged to expand its research base. As more evidence came in, the concern became alarm. In 1938, a special committee on expanded

Part of the extensive research facilities of the Langley Research Center, 1967.

facilities was formed, and it recommended the immediate creation of a second aeronautical research center, this one in California. The new laboratory was authorized by Congress in 1939. Less than a month later, on 14 September, ground was broken at Moffett Field, a Navy airfield 64 kilometers (about 40 miles) south of San Francisco, for what would become the Ames Aeronautical Laboratory (named after Joseph S. Ames, President of Johns Hopkins University, charter member and from 1927 to 1939 the dedicated chairman of NACA). The most impressive physical structure was the huge 18-meter by 24-meter wind tunnel, which dwarfed its parent "full-scale" tunnel at Langley. Also a beginning was made on an impressive array of high-speed research facilities.

But this was not enough; the war had begun in Europe on 1 September. On 19 October 1939, a second special committee, this one headed by Charles A. Lindbergh who had annually surveyed European aviation progress for the Army Air Corps, urgently recommended the building of a third laboratory, this one to specialize in research on air-

Ames Research Center, 1970. The big 40-x-80-foot wind tunnel is housed in the large building on the left.



craft power plants. In June 1940 Congress agreed. A site was made available at the Cleveland, Ohio, municipal airport, and construction began on facilities to develop and test aircraft piston engines and their components, study fuels and combustion, and perform research in fundamental physics, chemistry, and metallurgy of power plants. In 1943 research would belatedly begin on jet engines. After Dr. Lewis's death in 1948, the new facility was named the Lewis Flight Propulsion Laboratory. Wartime expansion came to Langley too; the War Department bought more acreage and NACA expanded into a west area with additional facilities that doubled the research capability.

World War II dramatically changed NACA—and aviation. For NACA it meant a drastic shift in both the nature and the size of its workload. For aviation it meant a big surge in speed and altitude of combat aircraft. NACA turned its attention to the short-term urgencies of finding practical fixes for problems in military aircraft already in production or on the drawing boards. The rapid increase in performance and the punishing demands of combat flying had also generated

Lewis Research Center, 1963. The laboratory is clustered on the near side of the Cleveland Airport.

or exaggerated a host of aerodynamic and structural problems. The workload was overwhelming. From 1941 through 1944 the NACA laboratories worked on 115 different airplane types. But results were quietly spectacular; fighter aircraft speeds and altitudes were increased, buffeting and stalls were cured, the tail design of the B-29 was saved from a dangerous weakness. The number of NACA personnel rose 13-fold from the 1939 figure, to 6800, and cadres from the Langley mother laboratory served as the administrative and research cores at the two new laboratories.

In the midst of expanding from one to three laboratories, NACA's work was effective. "The Navy's famous fighters—the Corsair, Wildcat, and Hellcat—are possible only because they were based on fundamentals developed by the NACA," Secretary of the Navy Frank Knox volunteered in 1943. "All of them use NACA wing sections, NACA cooling methods, NACA high-lift devices. The great sea victories that have broken Japan's expanding grip in the Pacific would not have been possible without the contributions of the NACA."

NEW HORIZONS

To the scientific community, the most exciting legacy of World War II was a glittering array of new technologies spawned by the massive war effort. Atomic energy, radar, antibiotics, the large rocket, radio telemetry, the computer, and the jet engine were war babies, lustily crying for expanded roles in the postwar world. The atomic age, the jet age, and the space age were at hand. They would shape the world's destiny in the next three decades, and heavily influence the rest of the century.

The world's political order had been drastically altered by the war. Much of Europe and Asia was in ashes. Old empires had crumbled; national economies were tottering perilously. Astride opposite sides of the world, towering like Colossi, stood the United States and the Soviet Union, newly made into superpowers. It soon became apparent that they would test each other's mettle many times before a balance of power stabilized. And each nation moved quickly to exploit the new technologies.

The atomic bomb was the most obvious and most immediately threatening technological change from World War II. Both superpowers sought the best strategic systems that could deliver the bomb across the intercontinental distances that separated them. Jet-powered

bombers were an obvious extension of the wartime B-17 and B-29, and both nations began designing and building them. The intercontinental rocket held great theoretical promise but seemed much farther down the technological road. Atomic bombs were bulky and heavy; a rocket to lift such a payload would be enormous in size and expense. The Soviet Union doggedly went ahead with attempts to build such rockets. The American military temporarily settled upon jet aircraft and smaller research and battlefield rockets. The Army imported Wernher von Braun and the German scientists who had created the wartime V-1 and V-2 rockets, and set them to overseeing the refurbishing and launching of V-2s at White Sands, New Mexico. With its contractor the Jet Propulsion Laboratory, the Army developed a series of battlefield missiles known as Corporal, Sergeant, and Redstone. The Navy designed and built the Viking research rockets. The freshly independent Air Force started a family of cruise missiles, from the jet Bomarc and Matador battlefield missiles to Snark and the ambitious rocket-propelled Navaho, which were intended as intercontinental weapons.

By 1951 progress on a thermonuclear bomb revived interest in the long-range ballistic missile. Two months before President Truman announced that the United States would develop the thermonuclear bomb, the Air Force contracted with Consolidated Vultee Aircraft Corporation (later Convair) to resume study, and then to develop, the Atlas intercontinental ballistic missile, a project that had been dormant for four years. During the next four years three intermediate range missiles—the Army's Jupiter, the Navy's Polaris, and the Air Force's Thor—and a second generation ICBM, the Air Force's Titan, had been added to the list of American rocket projects. All were accorded top national priority. Fiscal Year 1953 saw the Department of Defense for the first time spend more than $1 million on missile research, development, and procurement. Fiscal Year 1957 saw the amount go over the $1 billion mark.

The new postwar technologies were also having a dramatic effect on NACA. The swift rise of aircraft speeds and altitudes during the war had consumed the technological data base that NACA had so laboriously created in the 1930s. And now the jet engine, still in its infancy, portended another big surge in aircraft speed. Ahead lay the mysteries of the sound barrier, where strange things happened to fighter planes. Planes had crashed, men had died; by 1945 the need for information was urgent. In that year study began on a series of new wind tunnels; after many ups and downs the Unitary Plan was passed

by Congress in 1949. It allotted $75 million to NACA for new wind tunnels and started a wind-tunnel center (Arnold Engineering Development Center) for the Air Force.

But aerodynamic research faced serious physical obstacles. The wind tunnel, NACA's principal tool for aerodynamic research, yielded accurate data for subsonic and supersonic speeds but at transonic speeds (Mach 0.9 to 1.1) suffered a "choking" effect that garbled the data. Until this problem was remedied—if it could be remedied—other means had to be devised. In 1943 NACA took steps to meet the challenge.

The short-term effort involved flying test models to high altitudes in aircraft and dropping them, gathering flight data during their ballistic fall. This was only partially successful, since radar and telemetry were too primitive to return sophisticated data. Also the objects seldom exceeded Mach 1. The next step in this direction was to use rockets as motive power to launch models to transonic and supersonic speeds. Langley acquired a surplus naval station on Wallops Island, Virginia, for this purpose. It was called the Pilotless Aircraft Research Division. Later it became the Wallops Flight Center.

Wallops Flight Center's "little missile row" on the beach of Wallops Island, Va., from which sounding rockets and small satellites are launched.

The long-term measure was to plan and operate, in concert with the Air Corps and the Navy, the first of what was to become a highly successful series of special research aircraft. NACA's High-Speed Flight Research Station was established at Edwards, California, on Muroc Dry Lake. On 14 October 1947, Air Force Capt. Charles E. Yeager flew the X-1 aircraft faster than the speed of sound. The dreaded sound barrier was breached. On 20 November 1953, NACA's Scott Crossfield in the D-558-2 reached Mach 2. The X-1A, the X-2, the X-15—faster and higher they flew, peaking at Mach 6 (7272 kilometers per hour) in speed and 108 000 meters in altitude. Over a span of 22 years and more than 700 flights, the specially built research aircraft perilously, meticulously filled in the flight envelope for transonic and supersonic flight and provided the design data for generations of post-World War II military aircraft.

Meanwhile researchers at Langley had worked away at the intransigent transonic wind tunnels and by late 1950 John Stack and his team had come up with the answer—the "slotted throat," which eliminated the choking at or near the speed of sound and made the transonic tunnel an effective research tool. Within a year it had proved its worth; Richard Whitcomb discovered the "area rule," a subtle balancing of the volume of fuselage and wings which produced the minimum-drag aircraft at transonic speeds. Quickly applied to military fighters already in design and construction, it enabled them to be the first fighters to break the sound barrier in level flight.

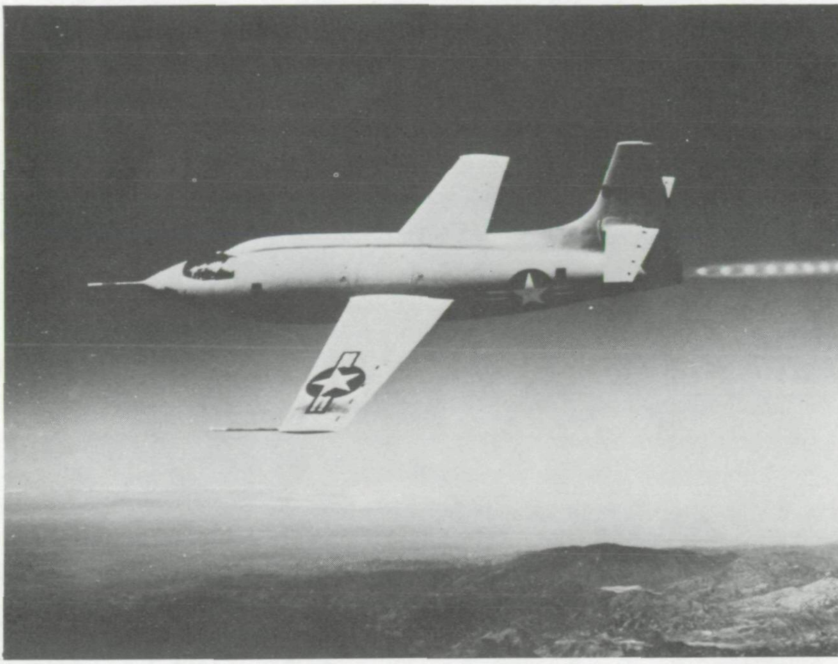
By the mid-1950s NACA had modern research facilities that had cost a total of $300 million, a staff totaling 7200. With each passing year it was enlarging its missile research in proportion to the old mission of aerodynamic research. Major NACA contributions to the military missile programs came in 1955–1957. Materials research led by Robert R. Gilruth at Langley confirmed ablation as the means of controlling the intense heat generated by warheads and other bodies reentering the Earth's atmosphere; H. Julian Allen at Ames demonstrated the blunt body shape as the most effective design for reentering bodies; and Alfred J. Eggers at Ames did significant work on the mechanics of ballistic reentry.

The mid-1950s saw America's infant space program burgeoning with promise and projects. As part of the U.S. participation in the forthcoming International Geophysical Year, it was proposed to launch a small satellite into orbit around the Earth. After a spirited design competition between the National Academy of Sciences–Navy proposal

(Vanguard) and the Army–Jet Propulsion Laboratory candidate (Explorer), the Navy design was chosen in September 1955 as (1) not interfering with the high-priority military missile programs, since it would use a new booster based on the Viking research rocket; and (2) having a better tracking system and more scientific growth potential. By 1957 Vanguard was readying its first test vehicles for firing. The U.S.S.R. had also announced it would have an IGY satellite; the space race was extending beyond boosters to payloads.

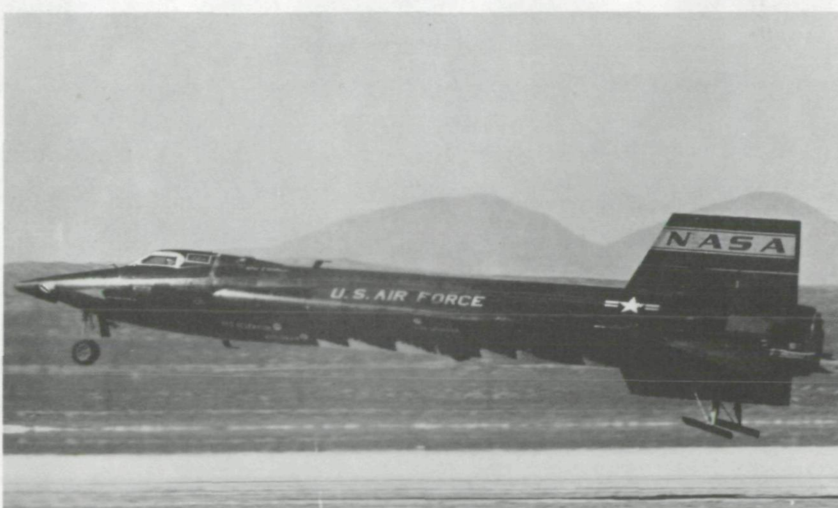
On the military front, space activity was almost bewildering. The missiles were moving toward the critical flight-test phase. Satellite ideas were proliferating, though mostly on a sub rosa planning basis; after Sputnik these would become Tiros, weather satellite; Transit, navigation satellite; Samos, reconnaissance satellite; Midas, missile early-warning satellite; Pioneer lunar probes; Discoverer research satellites. Payload size and weight were constant problems in all these concepts, with the limited thrust of the early rocket engines. Here the rapid advances in solid-state electronics came to the rescue by reducing volume and weight; with new techniques such as printed circuitry and transistors, the design engineers could achieve new levels of

Flight Research Center, 1967. At upper left is seen the edge of Muroc Dry Lake, whose rock-hard flat surface serves as the flight-test runway. In 1976, the center was renamed the Dryden Flight Research Center.



The X-1, first aircraft to fly faster than the speed of sound in level flight.

The X-15, which crowned the achievements of the research aircraft program with speeds over 7200 kilometers per hour and altitudes above 108 000 meters.



miniaturization of equipment. Even so, heavier payloads were obviously in the offing; more powerful engines had to be developed. So design was begun for several larger engines, topped by the monster F-1 engine, intended to produce 4450 kilonewtons of thrust—eight times the power of the engines that lifted the Atlas, Thor, and Jupiter missiles.

All this activity, however, was still on the drawing board, work bench, or test stand on 4 October 1957, when the "beep, beep" signal from *Sputnik I* was heard around the world. The Soviet Union had orbited the world's first artificial satellite.

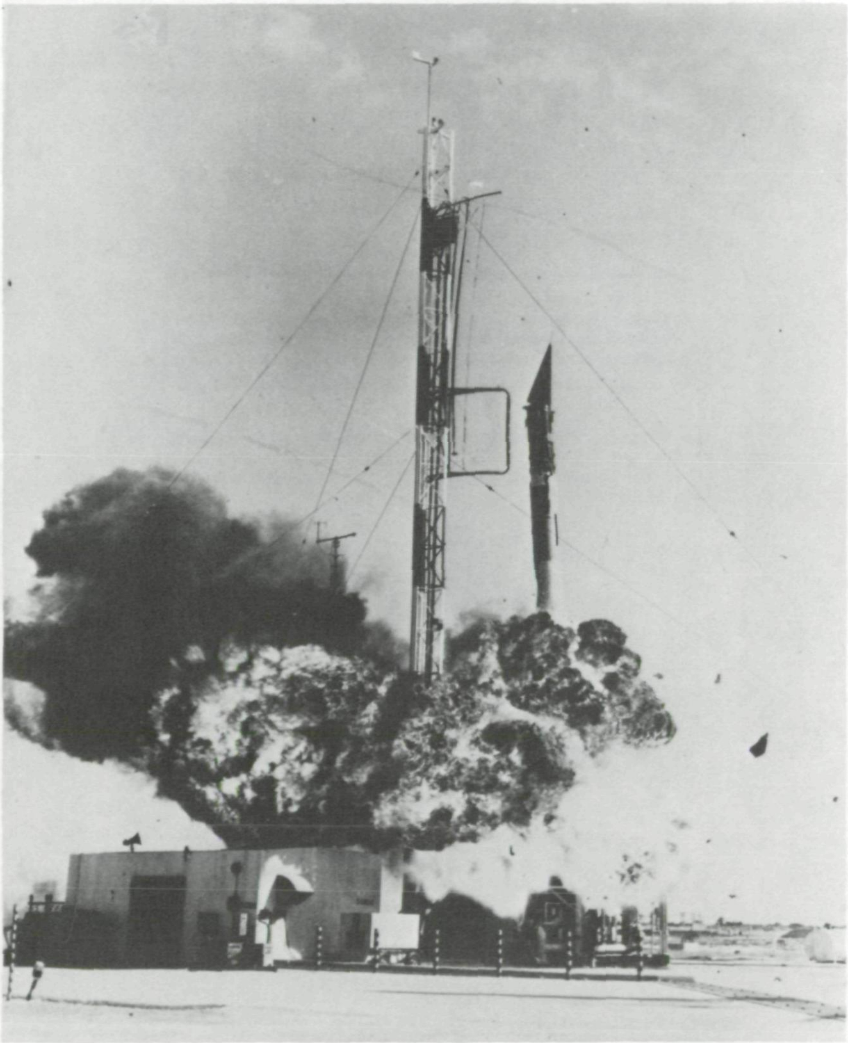
The American public's response to Sputnik was swift and widespread. It seemed equally compounded of alarm and chagrin. Our complacent certainty that this nation was always number one in technology had been rudely shattered. Not only had the Russians been first—although that was bad enough—but Sputnik weighed an impressive 83 kilograms against Vanguard's intended start at 1.4 kilograms and working up to 10 kilograms in later satellites. In a cold war environment, the contrast suggested undefined but ominous military implications.

Fuel for such apprehensions added up month after month. Less than one month after *Sputnik I*—on 3 November—the Russians launched *Sputnik II,* weighing a hefty 500 kilograms and carrying a dog as passenger. President Eisenhower, trying to dampen the growing firestorm of concern, assured the public of our as-yet-undemonstrated progress and denied there was any military threat in the Russian space achievements. As a counter the White House announced the impending launch in December of the first Vanguard test vehicle capable of orbit and belatedly authorized von Braun's Army research team in Huntsville to try to launch their Explorer-Jupiter combination. But pressures for dramatic action gathered rapidly. The media ballyhooed the carefully qualified announcement on Vanguard into great expectations of America's vindication. On 25 November Senator Lyndon B. Johnson, Senate Majority Leader, chaired the first meeting of the Senate Preparedness Investigation Subcommittee of the Senate Armed Services Committee. The hearings would review the whole spectrum of American defense and space programs.

Still the toboggan careened downhill. On 6 December 1957, the much-touted Vanguard test vehicle rose one meter from the launch platform, shuddered, and collapsed in flames. Its tiny 1.4-kilogram payload broke away and lay at the edge of the inferno, beeping impotently.

Clouds of gloom deepened into the new year. Then, finally, a small rift. On 31 January 1958, an American satellite at last went into orbit. Not Vanguard but the ABMA–JPL Explorer had redeemed American honor. True, the payload weighed only 14 kilograms against the last Sputnik's 500. But there was a scientific first; an experiment aboard the satellite reported mysterious saturation of its radiation

A ball of fire and flying debris mark the explosive failure of the first American attempt to launch a satellite on Vanguard, 6 December 1957.



counters at 965 kilometers altitude. Prof. James A. Van Allen, the scientist who had built the experiment, thought this suggested the existence of a dense belt of radiation around the Earth at that altitude. And American confidence perked up on 17 March when *Vanguard I* joined *Explorer I* in orbiting the Earth, this time in an orbit that was predicted to last 2000 years.

A moment of triumph with the announcement that *Explorer I* has become the first American satellite to orbit the Earth. Here a duplicate Explorer is held aloft in triumph by (left to right) Wernher von Braun of ABMA, James A. Van Allen of the State University of Iowa, and William H. Pickering of JPL.

Meanwhile, in these same tense months, both consensus and competition had been forming on the political front: consensus that a national augmented space program was essential; competition as to who would run such a program, in what form, with what priorities. The Department of Defense, with its component military services, was an obvious front runner. The Atomic Energy Commission, already working with nuclear warheads and nuclear propulsion, had some congressional support, particularly in the Joint Committee on Atomic Energy. And there was NACA.

NACA had devoted more and more of its facilities, budget, and expertise to missile research in the mid and late 1950s. Under the skillful leadership of James H. Doolittle, Chairman, and Hugh L. Dryden, Director, the strong NACA research team had come up with a solid, long-term, scientifically based proposal for a blend of aeronautic and space research. Its concept for manned spaceflight, for example, envisioned a ballistic-shaped spacecraft with a blunt reentry shape, backed by a world-encircling tracking system, and equipped with dual automatic and manual controls that would enable the astronaut gradually to take over more and more of the flying of his spacecraft. Also NACA offered reassuring experience of long, close working relationships with the military services in solving their research problems, while at the same time translating the research into civil applications. But NACA's greatest political asset was its peaceful, research-oriented image. President Eisenhower and Senator Johnson and others in Congress were united in wanting above all to avoid projecting cold-war tensions into the new arena of outer space.

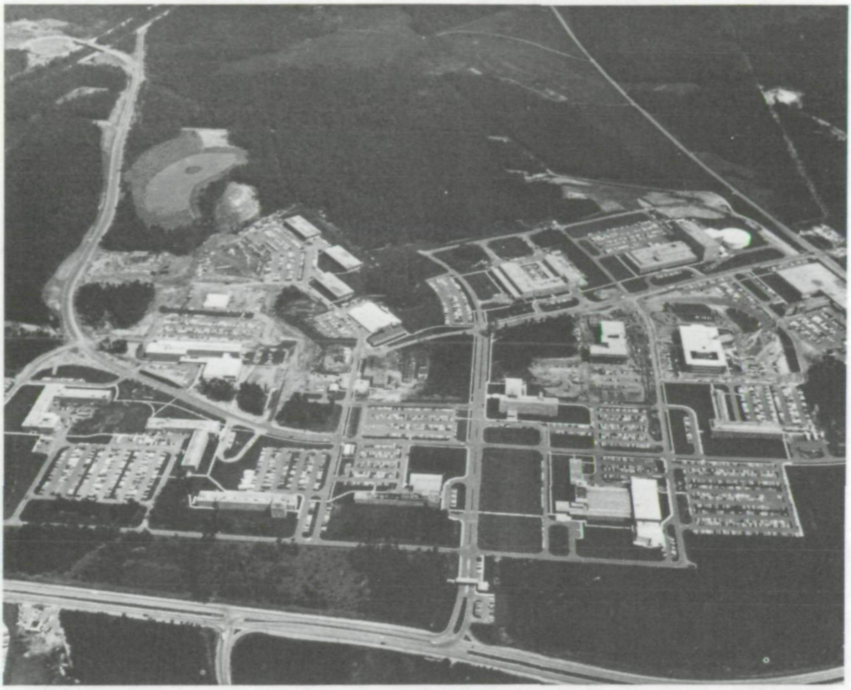
By March 1958 the consensus in Washington had jelled. The Administration position—largely authored by James R. Killian, in the new post of President's Special Assistant for Science and Technology—the findings of Johnson's Senate Preparedness Subcommittee, and the NACA proposal converged. America needed a national space program. The military component would of course be under DoD. But a civil component, lodged in a new agency, technologically and scientifically based, would pick up certain of the existing space projects and forge an expanded program of space exploration in close concert with the military. All these concepts fed into draft legislation. On 2 April 1958, the Administration bill for establishing a National Aeronautics and Space Agency was submitted to Congress; both Houses had already established select space committees; debate ensued, a number of refinements were introduced, mostly by Senator Johnson; and on 29 July

1958 President Eisenhower signed into law P.L. 85-568, the National Aeronautics and Space Act of 1958.

The act established a broad charter for civilian aeronautical and space research, with unique requirements for dissemination of information; absorbed the existing NACA into the new organization as its nucleus; and empowered broad transfers from other government programs. The National Aeronautics and Space Administration came into being on 1 October 1958.

All this made for a very busy spring and summer for the people in the small NACA Headquarters in Washington. First the space program effort, then the legislative effort. Once the general outlines of the new organization were clear, both a space program and a new organization had to be charted. In April Dryden brought Abe Silverstein, Assistant Director of Lewis Laboratory, to Washington to head the program planning. Ira Abbott, NACA Assistant Director for Aerodynamic Research, headed a committee to plan the new organization.

NASA's first high command. Hugh L. Dryden is presented his commission as Deputy Administrator by President Dwight D. Eisenhower with T. Keith Glennan, Administrator, looking on.



Goddard Space Flight Center, 1967. This is the main NASA center for the design and operation of scientific satellites.

In August President Eisenhower nominated T. Keith Glennan, President of Case Institute of Technology and former Commissioner of the Atomic Energy Commission, to be the first Administrator of the new organization, NASA, and Dryden to be Deputy Administrator. Quickly confirmed by the Senate, they were sworn in on 19 August. Glennan reviewed the planning efforts, approved most. Talks with the Advanced Research Projects Agency (ARPA) identified the military space programs that were space-science oriented and obvious transfers to the new agency. Plans were formulated for building a new center for space science research, satellite development, flight operations, and tracking. A site was chosen—two square kilometers of the Department of Agriculture's research center in Beltsville, Maryland. In March 1961 the Robert H. Goddard Space Flight Center (named for America's rocket pioneer) was dedicated.

II

The New Space Program

On 1 October 1958, the 170 people in Headquarters gathered in the courtyard of their building, the Dolley Madison House, to hear Glennan proclaim the end of the 43-year-old NACA and the beginning of NASA. The 8000 people, three laboratories (now renamed Research Centers) and two stations, with a total facilities value of $300 million and the annual budget of $100 million, were transferred intact to NASA. On the same day, by Executive Order the President transferred to NASA Project Vanguard, its 150-person staff, and remaining budget from the Naval Research Laboratory; lunar probes from the Army; lunar probes and rocket engine programs, including the F-1, from the Air Force; and a total of over $100 million of unexpended funds. NASA immediately delegated operational control of these projects back to the DoD agencies while it put its own house in order.

There followed an intense two-year period of organization, build-up, fill-in, planning, and general catch-up. Only one week after NASA was formed, Glennan gave the go-ahead to Project Mercury, America's first manned space flight. The Space Task Group, headed by Robert R. Gilruth, was established at Langley to get the job done. The new programs brought into the organization were slowly integrated into the NACA nucleus. Many space-minded specialists were drawn into NASA, attracted by the exciting new vistas. Long-range planning was accelerated; the first NASA Ten Year Plan was presented to Congress in February 1960. It called for an expanding program on a broad front: manned flight, first orbital, then circumlunar; scientific satellites to measure radiation and other features of the near-space environment; lunar probes to measure the lunar space environment and to photograph the Moon; planetary probes to measure and to photograph Mars and Venus; weather satellites to improve our knowledge of the Earth's broad weather patterns; continued aeronautical research; and development

of larger launch vehicles for lifting heavier payloads. Cost of the program was expected to vary between $1 billion and $1.5 billion a year over the 10-year period.

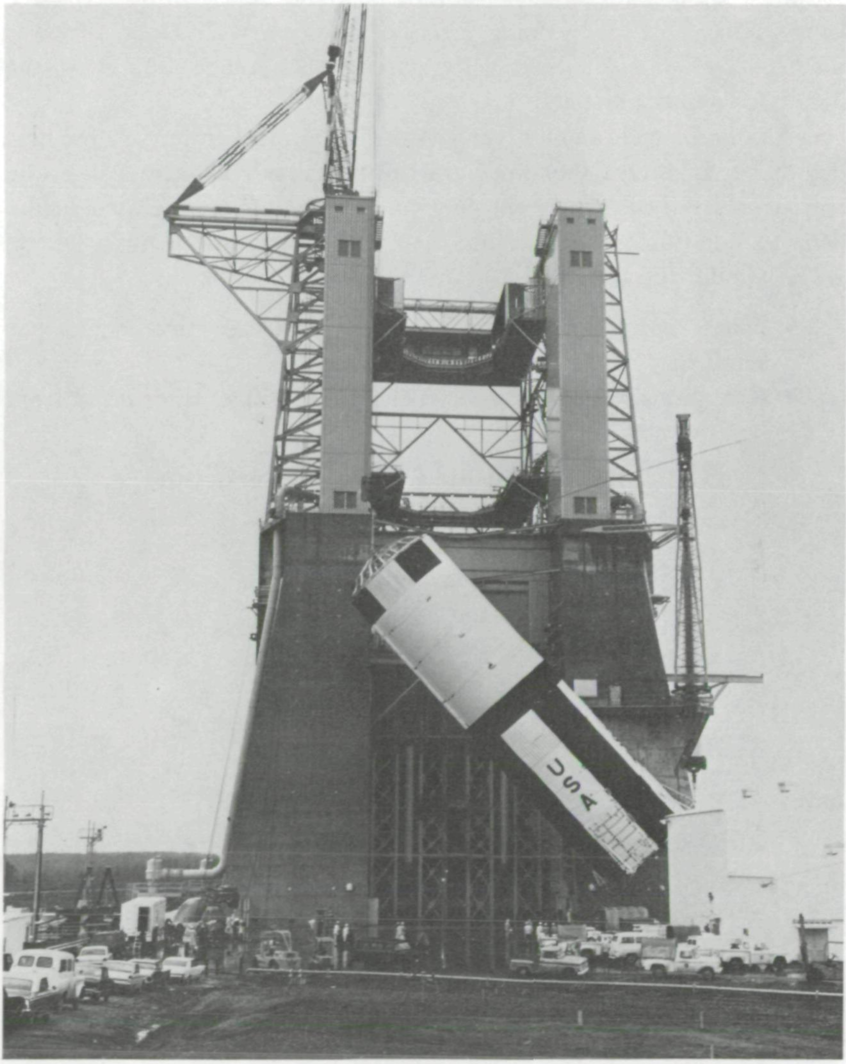
If NASA was to conduct such a program, it obviously needed capabilities it did not have. To that end Glennan sought to acquire the successful Army team that had launched America's first satellite—the Army Ballistic Missile Agency at Huntsville, Alabama, and its contractor, the Jet Propulsion Laboratory in Pasadena, California. The Army balked at losing the Huntsville group, claiming it was indispensible to the Army's military rocket program. Glennan for the time being had to compromise: ABMA would do work on NASA programs as requested. The Army grudgingly gave up JPL. On 3 December 1958, an Executive Order transferred, effective 31 December, the government-owned plant of JPL and the Army contract with the California Institute of Technology, under which JPL was staffed and operated. Glennan renewed his bid for ABMA in 1959; protracted Army resistance was finally overcome and on 15 March 1960 ABMA's 4000-man

Jet Propulsion Laboratory, 1963. This contract facility has been the mainstay of NASA's lunar and planetary programs.

Development Operations Division, headed by Wernher von Braun, was transferred to NASA along with the big Saturn booster project.

As the Ten Year Plan took shape and the capability grew, there were many other gaps to be filled. NASA was going to be markedly different from NACA in two important ways. First, it was going to be operational as well as R&D. That is, it would not only design and build

Marshall Space Flight Center, 1965, where a ground test model of the first stage of Saturn V was being hoisted onto the test stand.



launch vehicles and satellites but it would launch them, operate them, track them, acquire data from them, and interpret the data. Second, it would do the greater part of its work by contract rather than inhouse as NACA had done. The first of these required tracking sites in many countries around the world, as well as construction of tracking facilities —antennas, telemetry equipment, computers, radio and landline communications networks, etc. The second required the development of a larger and more sophisticated contracting operation than NACA had needed. In the first years, NASA leaned heavily on DoD for contracting assistance. Since its industrial contractors would be the same aerospace firms who were already doing extensive business with DoD, this was practical and workable, especially since NASA adopted most of the DoD procurement system.

The problem of launch vehicles occupied much attention in these first years. A family of existing and future launch vehicles had to be structured for the kinds of missions and spacecraft enumerated in the plan. In addition to the existing Redstone, Thor, and Atlas vehicles, NASA would develop

- Scout, a low-budget solid-propellant booster that could put small payloads in orbit;
- Centaur, a liquid-hydrogen-fueled upper stage, transferred from

The worldwide satellite tracking network, 1974.

LEGEND

● SPACEFLIGHT TRACKING & DATA NETWORK [STDN] FACILITIES

▲ DEEP SPACE NETWORK [DSN] FACILITIES

DoD, that promised higher thrust and bigger payloads for lunar and planetary missions;

- Saturn, which was expected to be flying in 1963 (with the proper upper stages it would put upwards of 23 000 kilograms in Earth orbit);
- Nova, several times the size of Saturn, to be started later in the decade for the more ambitious manned lunar flights anticipated in the 1970s.

In addition, work would continue with the Atomic Energy Commission on the difficult but enormously promising nuclear-propelled upper stage, Nerva, and on the Snap family of long-life power producers.

As much as larger boosters were needed, an even more immediate problem was how to improve the reliability of the existing boosters. By December 1959 the United States had attempted 37 satellite launches; less than one third attained orbit. Electrical components, valves, turbopumps, welds, materials, structures—virtually everything that went into the intricate mechanism called a booster—had to be redesigned or strengthened or improved to withstand the stresses of launch. A new order of perfection in manufacturing and assembly had to be instilled in workmen and managers. Rigorous, repeated testing had to verify each component, then subassembly, then total vehicle. That bugaboo of the engineering profession—constant fiddling and changing in search of perfection—had to be harnessed to a compromise of reliability. And since the existing vehicles were DoD products, NASA had to persuade DoD to enforce these rigorous standards on its contractors.

That was only one of the areas in which close coordination between NASA and DoD was essential and effective. In manned spaceflight, for example, there were essentially four approaches to putting man into space:

(1) the research airplane—the Air Force and NASA were already well into this program, leading to the X-15;
(2) the ballistic vehicle—NASA's Project Mercury embodied this approach, with Air Force launch vehicles and DoD support throughout;
(3) the boost-glider—the Air Force had inaugurated the Dyna-Soar project (later renamed the X-20) in November 1957. A manned glider would be boosted into shallow Earth orbit, bounce in and out of the top of the Earth's atmosphere for

part or all of a revolution of the Earth, and land like an airplane. In May 1958 NACA had agreed to help with the technical side of the project; NASA continued that support;

(4) the lifting body—a bathtub-like shape proposed by Alfred J. Eggers of Ames Laboratory; as a reentry shape it would be midway between an airplane configuration and the ballistic shape, developing moderate lift during reentry and landing like an airplane. This approach would be deferred for a few years before being explored by the Air Force and NASA.

In another area, communications satellites, DoD had its Courier program, a low-altitude, militarily secure communications satellite; it also had Advent, intended to be put into equatorial synchronous orbit by the Atlas-Centaur booster and provide global communications for the military. NASA had a passive communications satellite, Echo, a 30-meter inflatable sphere from which to bounce radar signals as a limited communications relay and, over a period of time and with accurate tracking, to plot the variations in air density at the top of the atmosphere by following the vagaries of its orbit. It had been agreed that NASA would leave active communications satellites—those that picked up, amplified, and rebroadcast radio signals from one point on Earth to another—to DoD. But this did not answer for long, By 1960 the American Telephone and Telegraph Company was asking NASA to launch its low-level, active communications satellite, Telstar. NASA also had another proposal for medium altitude (roughly 17 900-kilometer orbit) communications satellites.

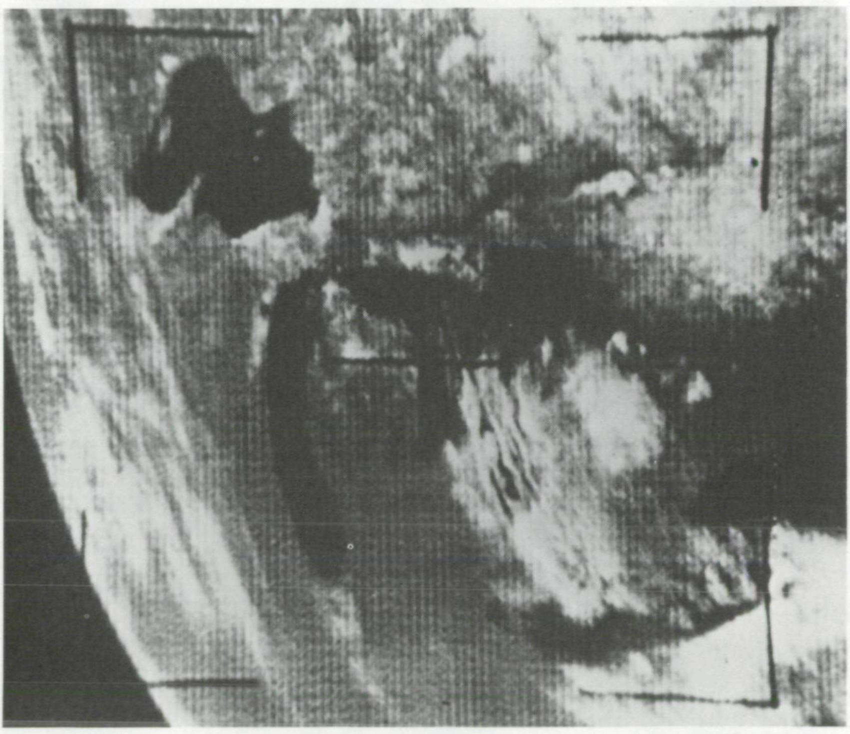
The AT&T proposal raised a fundamental problem: would industry develop communications satellites entirely with its own money or would the government fund its own research? NASA sought and received presidential approval to go both ways—to provide reimbursable launches to industry and to do its own communications satellite research. First there was Relay, the medium-altitude repeater satellite. Beyond lay the imaginative proposal from Hughes Aircraft Company for Syncom, a synchronous-orbit satellite—one that would fly at 35 000-kilometer altitude, where distance, gravity, and velocity combined to place a satellite permanently over the same spot on Earth; by virtue of the lofty orbit, three of these satellites could cover the entire Earth and require only a handful of ground stations.

By the time of the presidential election of 1960 the worst pangs of reorganization, absorption, redefinition, and planning were over. Pro-

grams were meshing with each other; contracting for large projects was becoming routine; the initial absorption of DoD programs had been completed; and a viable organization was in business.

There were operational bright spots as well. True, launch vehicles were still fickle and unpredictable—7 out of 17 launches failed in 1959. But finally in August 1959, NASA launched its first satellite that functioned in all respects (*Explorer VI*); *Pioneer V,* launched on 11 March 1960 and intended to explore interplanetary space between Earth and Venus, communicated out to a new distance record, 35.7 million kilometers; the first of the prototype weather satellites, *Tiros I,* launched on 1 April 1960, produced 22 500 photos of Earth's weather; *Echo I,* the first passive communications satellite, was launched 12 August 1960, inflated in orbit, and provided a passive target for bouncing long-range communications from one point on Earth to another. Perhaps as important, millions of people saw in the night sky the moving pinpoint of light that was Echo and were awed by the experience.

An early Tiros weather photo of the Great Lakes area on a wintry day.



In late 1960 politics bemused the space program. Although not a direct campaign issue in the presidential campaign, the space program found little reassurance of its priority as an expensive new item in the Federal budget. After John F. Kennedy was narrowly elected, the uncertainty deepened. Jerome B. Wiesner, the President-elect's science adviser, chaired a committee which produced a report both critical of the space program's progress to date and skeptical of its future. Who would be the new Administrator? What, if any, priority would the fledgling space program have in a new, on-record-hostile administration?

Then, once again, challenge and response. On 12 April 1961, Soviet Cosmonaut Yuri Gagarin rode *Vostok I* into a 301-by-174-kilometer orbit of the Earth. After one orbit he reentered the atmosphere and landed safely. Man had flown in space. Gagarin joined that elite pantheon of men who were the first to do the undoable—the Wright brothers, Lindbergh, now Gagarin. There was faint consolation on 5 May 1961, when Mercury essayed its first manned space flight. Astronaut Alan B. Shepard, Jr., rode a Redstone booster in his *Freedom* 7 Mercury spacecraft for a 15-minute suborbital flight and was picked out of the water 487 kilometers downrange. Success, yes; a good beginning, yes. But Gagarin had flown around the Earth—40 000 kilometers against Shepard's 487. His Vostok weighed 4730 kilograms in orbit, contrasting with Mercury's 953 kilograms in suborbit. Gagarin had had about 89 minutes in weightlessness—the mysterious zero-gravity condition which had supplanted the sound barrier as the great unknown. Shepard experienced five minutes of weightlessness. By any unit of measurement, the United States was clearly still behind, especially in the indispensable prerequisite of rocket power. The new President could only say, gloomily: "We are behind . . . . the news will be worse before it is better, and it will be some time before we catch up."

The public reaction was less emphatic than after *Sputnik I* but congressional concern was strong. Robert C. Seamans, Jr., NASA's Associate Administrator and general manager, was hard put to restrain Congress from forcing more money on NASA than could be effectively used.

President Kennedy was especially concerned. His Inaugural Address in January had rung with an eloquent promise of bold new initiatives that would "get this country moving again." The succeeding three months had been distinguished by crushing setbacks—the Bay of Pigs invasion fiasco and the Gagarin flight. As one of several searches for new initiative, the President asked his Vice President, Lyndon B.

Johnson, to head a study of what would be required in the space program to convincingly surpass the Soviets. Johnson, the only senior White House figure in the new Administration with prior commitment to the space program, found strong support waiting in the wings. James E. Webb, new Administrator of NASA, had an established reputation as an aggressive manager of large enterprise, both in industry and in the Truman Administration as Director of the Bureau of the Budget and Undersecretary of State. Backed by the seasoned technical judgment of Dryden, his deputy, and Seamans, his general manager, Webb moved vigorously to accelerate and expand the central elements of the NASA Ten Year Plan.

The largest single concept in that plan had been manned circumlunar flight. Now the question became: could this country rally quickly enough to beat the Soviets to that circumlunar goal? The considered technical estimate was: not for sure. But if we went one large step further and escalated the commitment to manned lunar landing and return, it became a new ball game. Both nations would have to design and construct a whole new family of boosters and spacecraft; this would be an equalizer in terms of challenge to both nations and the experts were confident that the depth and competence of the American government-industry-university team would prove superior. In this judgment they found a strong ally in the new Secretary of Defense, Robert S. McNamara.

But Webb and his advisers were not content with a one-shot objective. The goal, they said, was a major space advance on a broad front —manned space flight, yes, but also boosters, communications satellites, meteorological satellites, scientific satellites, planetary exploration.

This was the combined proposal presented to the Vice President and approved and transmitted by him to the President. It was the best new initiative the President had seen. So it was that on 25 May 1961 the President stood before a joint session of Congress and proposed a historic national goal:

> Now is the time to take longer strides—time for a great new American enterprise—time for this nation to take a clearly leading role in space achievement, which in many ways may hold the key to our future on earth. . . .
>
> I believe this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish.

The President correctly assessed the national mood. Editorial support was widespread. Congressional debate was perfunctory, given the size of the commitment. The decision to land a man on the Moon was endorsed virtually without dissent.

THE LUNAR COMMITMENT

NASA was exhilarated but awed. Dryden had returned from a White House meeting to tell his staff that "this man" [Webb] had sold the President on landing a man on the Moon. Gilruth, immersed in what seemed to be big enough problems in the relatively modest Project Mercury, was temporarily aghast. But the die was cast. The nation had accepted the challenge to its largest technological enterprise, dwarfing even the wartime Manhattan Project for developing the atomic bomb and the postwar crash development of strategic missiles.

The blank check was there; the way to use it was far from clear. Since 1958, studies had been underway on a circumlunar manned flight. Since 1959, George M. Low, head of the manned space flight office in Headquarters, had ramrodded a series of progressively more detailed studies on the requirements for a manned lunar landing on the Moon. Those studies had established a broad confidence that no major technological or scientific breakthroughs were needed to get a man to the Moon or even to land and return him. But there were some operational unknowns; the blank check caused them suddenly to loom larger:

- the earlier assumption had been that one simply built a big enough booster, flew directly to the Moon, landed a large vehicle on the lunar surface, and returned some part of it directly to Earth. But there were wide scientific disagreements as to the nature of the lunar surface. Was it solid "ground," strong enough to support such a load? Or was it many feet of dust, in which a spacecraft would disappear without a trace? Or was it something in between? There were operational problems too: could the crew and ground control possibly handle the enormous peak of work that would bunch together in the landing phase of a direct-ascent mission?
- the early alternative seemed to be that one boosted pieces of a lunar vehicle into Earth orbit, assembled and refueled them there, and took off for a direct landing on the Moon. This too

President John F. Kennedy on 25 May 1961 recommended to a joint session of Congress that the United States undertake the challenge of landing men on the Moon and returning them to Earth in the decade of the 1960s.

was fraught with hazards: could payloads rendezvous in Earth orbit? Could men assemble complex equipment in the demanding environment of space? Could such operations as refueling with volatile fuels—hazardous enough on Earth—be safely performed in space?

Some points were clear. The very massiveness of the effort would make this program different in kind from anything NASA had attempted. New organizational modes were essential; no one center could handle this program. A much stronger Headquarters team would be needed, coordinating the efforts of several centers and riding herd on an enormous mobilization of American industry and university effort.

Also, there were long-lead-time problems that needed to be worked on irrespective of later decisions. One of these was three years under way —a big engine. Work on the 4400-kilonewton-thrust F-1 engine would be accelerated. Another was a navigation system; accurate vectoring

of a spacecraft from Earth to a precise point on a rapidly moving Moon 370 000 kilometers away was a formidable problem in celestial mechanics. Therefore the first large Apollo contract was let to the Massachusetts Institute of Technology and its Instrumentation Laboratory, headed by C. Stark Draper, to begin study of this inscrutable problem and to develop the requisite navigational system.

The basic spacecraft could be delineated—the one in which a crew would depart the Earth, travel to the Moon, and return. And, building on Gemini design, it should have a baggage car—a jettisonable service module housing the propulsion, expendable oxygen, etc. The Space Task Group was hard at work on these with its left hand, while its main effort on Mercury went forward. That left hand had to be strengthened.

A whole new system of Earth-based logistics was needed for this scale of effort. From factory to launch, everything had outstripped normal sizes and normal transportation. There would have to be new factories, new mammoth test stands, huge launch complexes. Railroads and highways could not handle the larger components. Ship transportation seemed the only answer. A massive facility design and site location program had to get under way even before the final configuration of the vehicle was decided. Limited in capability in the facilities and construction area, NASA decided to call on the tested resources of the Army Corps of Engineers. It proved to be one of the wiser decisions in this hectic period.

As planning went forward in 1961 and 1962, order gradually emerged. A new concept for how to get to the Moon painfully surfaced: lunar-orbit rendezvous. A small group at Langley, headed by John C. Houbolt, had studied the trade-offs of direct ascent, Earth-orbit rendezvous, and other possibilities. They had been increasingly struck with the vehicle and fuel economics of this mission profile: after stabilizing in Earth orbit, a set of spacecraft went to orbit around the Moon, and, leaving the mother spacecraft in lunar orbit, dispatched a smaller craft to land on the lunar surface, reconnoiter, and rejoin the mother craft in lunar orbit for the return to Earth. Over a period of two years they refined their complex mathematics and argued their case. As time became critical for definition of the launch vehicle, they argued their case before one NASA audience after another. Finally Houbolt, in a bold move, went outside of "channels" and got the personal attention of Seamans. This was a decision of such importance to the total program that imposed decision was not enough—the major elements of NASA had to be won over and concur in the final technical judgment.

Dismissed at first as risky and very literally "far out," lunar orbit rendezvous gradually won adherents. In July 1962 D. Brainerd Holmes, NASA Director of Manned Space Flight, briefed the House space committee on lunar orbit rendezvous, the chosen method of going to the Moon.

Once made, this decision permitted rapid definition of the Apollo spacecraft combination. Launch vehicle configuration had been arrived at seven months earlier. The objective would be to put a payload of nearly 136 000 kilograms in Earth orbit and 45 000 kilograms in orbit around the Moon. To do this required a three-stage vehicle, the first stage employing the F-1 engine in a cluster of five, to provide 33 000 kilonewtons of thrust at launch. The second stage would cluster five of a new 890-kilonewton-thrust liquid hydrogen and liquid oxygen engine (the J-2). The third stage, powered by a single J-2 engine, would boost the Apollo three-man spacecraft out of Earth orbit and into the lunar gravitational field. At that point the residual three-spacecraft combination would take over—a Command Module housing the astronauts, a Service Module providing propulsion for maneuvers, and a two-man Lunar Module for landing on the Moon. The engine on the Service Module would ignite to slow the spacecraft enough to be captured into lunar orbit; the fragile Lunar Module would leave the mother craft and descend to land its two passengers on the Moon. After lunar reconnaissance, the astronauts would blast off in the top half of the Lunar Module to rejoin the mother craft in lunar orbit, and the Service Module would fire up for return to Earth.

A smaller launch vehicle, which would later be dubbed the Saturn IB, would be built first and used to test the Apollo spacecraft in Earth orbit. Even this partial fulfillment of the Apollo mission would require a first stage of 7300 kilonewtons of thrust and a high-energy liquid oxygen-liquid hydrogen second stage.

The grand design was now complete. But in the articulating of it, vast gaps in space experience and technology were revealed. At three critical points the master plan depended on successful rendezvous and docking of spacecraft. Although theoretically feasible, it had never been done and was not within the scope of Project Mercury. How could practical experience be gained with rendezvous and docking short of an intricate, hideously expensive, and possibly disastrous series of experiments with Apollo hardware? Men would, hopefully, land and walk upon the Moon. But could men and their equipment function in space outside the artificial and confining environment of their space-

craft? Other systems and other questions could be engineered to solution on Earth, but the ultimate questions here could only be answered in space. We had bitten off more than we could chew. Clearly something was needed between the exploratory confines of Mercury and the grand design of Apollo. The gap was too great to jump when men's lives were at stake.

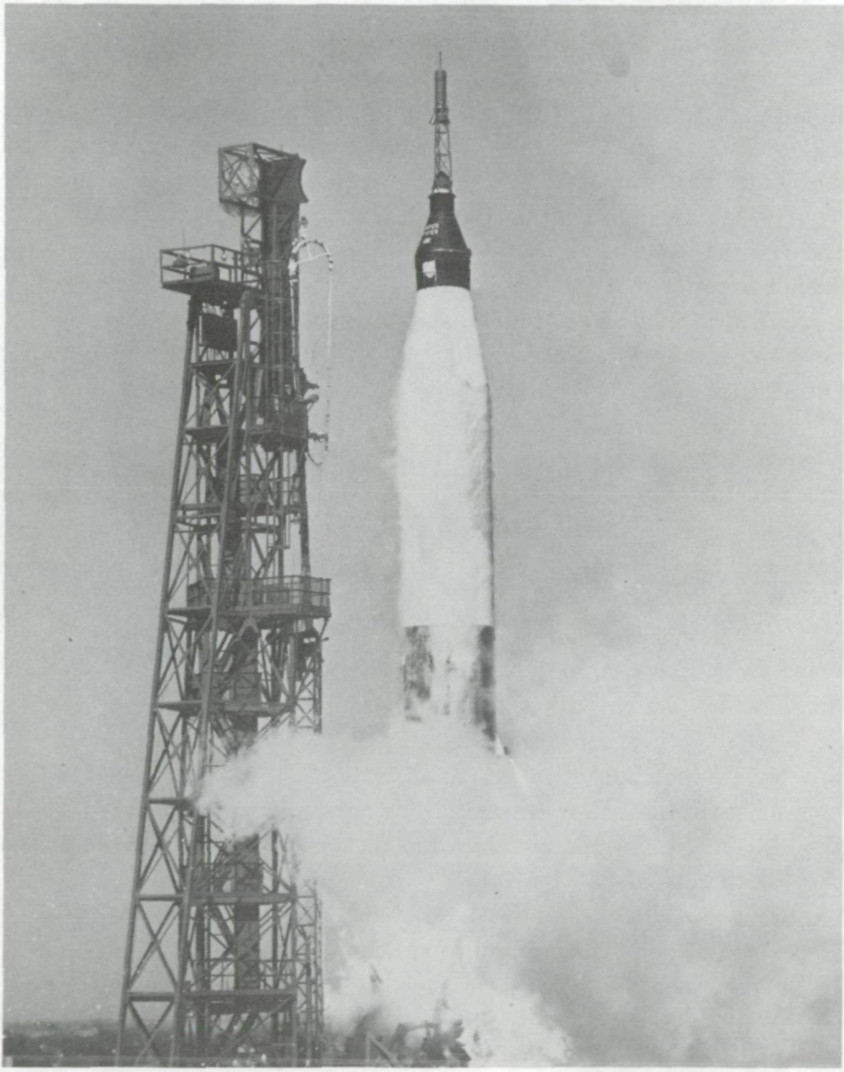
Even Mercury sometimes seemed a very big mouthful to chew. But slowly, stubborn problem after stubborn problem yielded. The second suborbital flight, *Liberty Bell 7,* was launched on 21 July 1961; its 16-minute flight went well, though on landing the hatch blew off prematurely and the spacecraft sank just after Astronaut Virgil I. Grissom was hoisted to safety in a rescue helicopter. In September the unmanned Mercury-Atlas combination was orbited successfully and landed where it was supposed to, east of Bermuda. On 29 November the final test flight took chimpanzee Enos on a two-orbit ride and landed him in good health. The system was qualified for manned orbital flight. And on 20 February 1962, Astronaut John H. Glenn, Jr., became the first American to orbit the Earth in space. *Friendship* 7 circled the Earth three times; Glenn flew parts of the last two orbits manually because of trouble with his autopilot.

The United States took its astronaut heroes to its heart with an enthusiasm that bewildered them and startled NASA. Their mail was enormous; hundreds of requests for personal appearances poured in. Glenn had a rainy parade in Washington and addressed a joint session of Congress. On 1 March four million people in New York showered confetti and ticker tape on him and fellow astronauts Shepard and Grissom. Nor was the event unnoticed by the competition. President Kennedy announced the day after the Glenn flight that Soviet Premier Nikita Khrushchev had congratulated the nation on its achievement and had suggested the two nations "could work together in the exploration of space." The results of this exchange were a series of talks between Dryden of NASA and Anatoliy A. Blagonravov of the Soviet Academy of Sciences. By the end of the year they had agreed to exchanges of meteorological and magnetic field data and some communications experiments.

A big year for the young American space program, 1962. Two more Mercury flights, Carpenter for three orbits, then Schirra for six. The powerful Saturn booster made its first two test flights, both successful. The first active communications satellite, *Telstar I,* was launched for AT&T by NASA; later NASA's own Relay communications satellite

was orbited; and the first international satellite, Britain's *Ariel I,* was launched by NASA to take scientific measurements of the ionosphere. *Mariner II* became the first satellite to fly by another planet; on 14 December it passed within 34 400 kilometers of Venus and scanned the surface of that cloud-shrouded body, measuring its temperatures. Then

Astronaut John H. Glenn, Jr., aboard his Mercury spacecraft *Friendship 7,* rose off the launch pad at Cape Canaveral on 20 February 1962 to become the first American to orbit the Earth.



it continued into orbit about the Sun, eventually setting a new communications distance record of 89 million kilometers. The fifth and sixth Tiros meteorological satellites were placed in orbit and continued to report the world's weather. So successful had Tiros been that the R&D program had quickly become semioperational. The Weather Bureau was regularly integrating Tiros data into its operational forecasting and was busy planning a full-scale weather satellite system which it would operate. And the hard work on booster reliability began to pay off—18 successes to 9 failures or partial successes.

Not that all was sweetness and light. The Ranger, designed to photograph the Moon while falling to impact the lunar surface, was in deep trouble. A high-technology program at the edge of the state of the art, Ranger closed the year with five straight failures and another one would come in 1963. JPL, the NASA agent; Hughes Aircraft Co., the contractor; and NASA Headquarters came under heavy pressure from Congress. Studies were made; reorganization realigned JPL and contractor to firm commitment to the project; NASA dropped the science experiments, and the last three Ranger flights were spectacularly successful, providing close-in lunar photography that excelled the best telescopic detail of the Moon from Earth by 2000 times and dispelled many of the scare theories about the lunar surface.

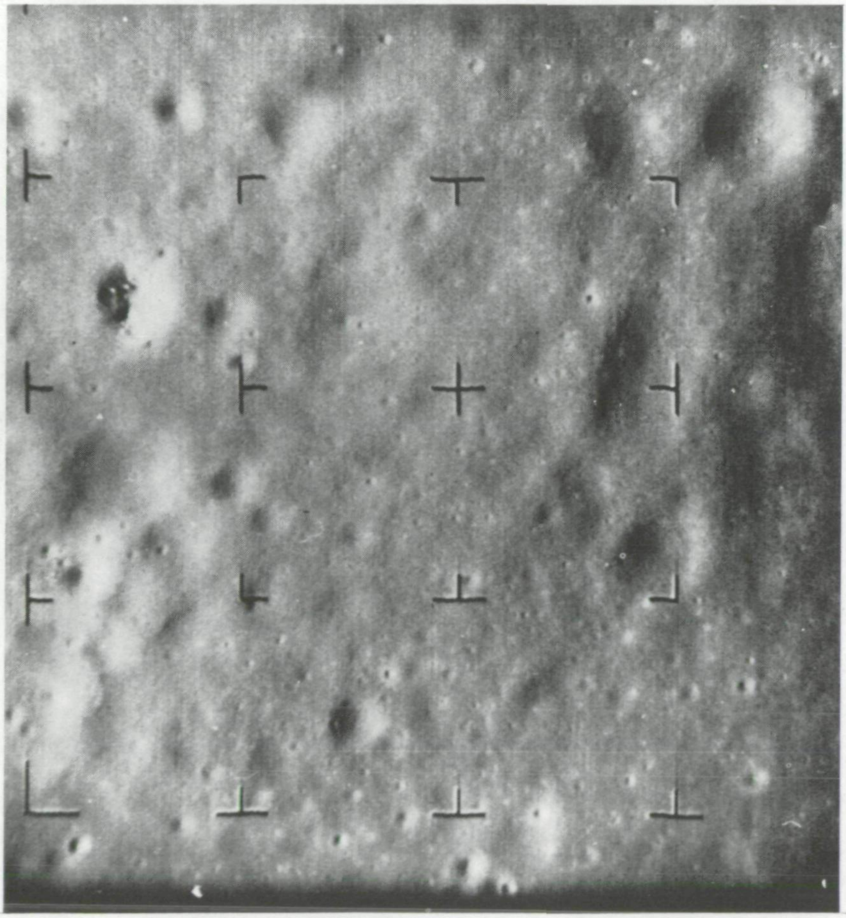
As the dimensions of Apollo began to dawn on Congress and the scientific community, there were rumbles: Apollo would preempt too much of the scientific manpower of the nation; Apollo was an "other worldly" stunt, directed at the Moon instead of at pressing problems on Earth. Administrator Webb met both of these caveats with positive programs.

In acknowledgment of the drain on scientific manpower, Webb won White House support for a broad program by NASA to augment the scientific manpower pool. Thousands of fellowships were offered for graduate study in space-related disciplines, intended to replace or at least supplement the kinds of talent engulfed by the space program. Complementing the fellowships was an even more innovative program—government-financed buildings and facilities on university campuses for the new kinds of interdisciplinary training that the space program required.

From a modest beginning in 1962, by the end of the program in 1970 NASA had footed the bill for the graduate education of 5000 scientists and engineers at a cost of over $100 million, had spent some $32 million in construction of new laboratory facilities on 32

university campuses, and had given multidisciplinary grants to some 50 universities that totaled more than $50 million. The program marked a new direction in the government's recognition of its responsibility for impact of its program on the civilian economy and a new dimension of cooperation between the university and the government. In part as a result of these new capabilities in the universities, NASA contracts and grants for research by universities rose from $21 million in 1962 to $101 million in 1968. The NASA university program proved very

Ranger VII took this photograph of the lunar surface from an altitude of about 6 kilometers, 2.3 seconds before it crashed. The crater in the upper left corner measured about 91 meters in diameter and had an angular rock mass in its center which might have been the cause of the crater.

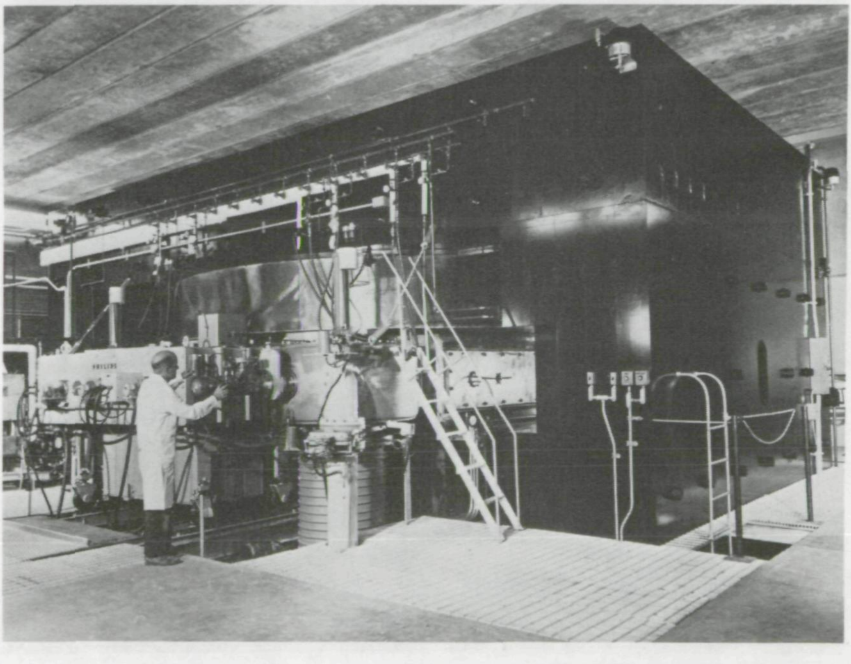


effective: on the political side it reduced tensions between NASA and the scientific/engineering community; on the score of national technology capability it enlarged and focused a large segment of the research capabilities of the universities.

To refute the other charge—that Apollo would serve only its own ends and not the broader needs of the nation's economy—Webb created the NASA technology utilization program in 1962. Its basic purpose was to identify and hold up to the light the many items of space technology that could be or had been adapted for uses in the civilian economy. By 1973 some 30 000 such uses had been identified and new ones were rolling in at the rate of 2000 a year.

But the program went beyond that: a concerted effort was made in every NASA center not only to identify possible transfers of space technology but to use NASA technical people and contractors to explore

This synchrocyclotron in the Space Radiation Effects Laboratory is operated for NASA by the College of William and Mary, the University of Virginia, and Virginia Polytechnic Institute. Generating 600 million electron volts, this nuclear giant employs a large electromagnet to accelerate positive hydrogen ions to eight tenths the speed of light; the particles are then extracted for use in high-energy radiation experiments.



and even perform prototype research on promising applications. NASA publications described all these potential applications to researchers and industry; seven regional dissemination centers were established to work directly with industry on technical problems in the adaptation of space technology; in 1973 some 2000 companies received direct help and another 57 000 queries were answered. New products ranged from quieter aircraft engines to microminiaturized and solid-state electronics that revolutionized TV sets, radios, and small electronic calculators. NASA's computer software programs enabled a wide range of manufacturers to test the life history of new systems—see predictions of problems that could develop, how the systems would perform, how long they would last, etc. Many other facets of the space program were important to the quality and sustenance of life for citizens of the United States and the world:

Communications: Within a decade the communications satellite proved itself to be a reliable, flexible, cost-effective addition to long-range communications. The Communications Satellite Corporation became a solid financial success, with 114 000 stockholders. As manager of the International Telecommunications Satellite Consortium, it had shared access to the global satellite system with 82 other nations who had become members of the Consortium. Its array of sophisticated Intelsat communications satellites bracketed the world from synchronous orbit. Before these satellites existed, the world's total capability for transoceanic telephone calls was 500 circuits; in 1973 the Intelsat satellites alone offered more than 4000 transoceanic circuits. Real-time TV coverage of events anywhere in the world—whether Olympics, wars, or coronations—had become a commonplace in the world's living rooms. Satellite data transmission enabled industries to control far-flung production and inventories, airlines to have instantaneous coast-to-coast reservation systems, large banks to have nationwide data networks. And this communications revolution was only beginning. The next generation of communications satellite—Intelsat V—would start operations in 1976 with five times the capacity of its predecessor Intelsat IV and a life expectancy of ten years in orbit. About 1976 the Maritime Administration would embark on a global ship-control system operated by means of satellites. Experiments with ATS satellites would continue to refine the life-saving biomedical communication network which links medical personnel and medical centers across the nation. Especially valuable to isolated and rural areas, the network would afford them real-time access to expert diagnosis and prescription of treatment.

Weather forecasting: Like its brother the communications satellite, the weather satellite had in less than a decade become an established friend of people around the world. Potentially disastrous hurricanes such as Camille in August 1969 and Agnes in June 1972 were spotted, tracked, and measured by the operational weather satellite network of the National Oceanic and Atmospheric Administration (NOAA). The real-time knowledge of the storm's position, intensity, and track made possible accurate early warning and emergency evacuation that saved hundreds of lives and millions of dollars in property damage. Near-global rainfall maps were being produced by 1973 from data acquired by NASA's *Nimbus 5*. Not only did the heat-release information contained in such data markedly improve long-range weather forecasting but the data were of immediate value in agriculture, flood control, etc. Ice-movement charts for the Arctic and Antarctic regions were extending shipping schedules in these areas by several months each year.

Medicine: NASA's experience in microminiaturized electronics and in protecting and monitoring the health of astronauts during space flights generated hundreds of medical devices and techniques that could save lives and improve health care. Multidisciplinary teams of space technicians and medical researchers were successful in developing long-duration heart pacers, for instance. Implanted in the patient's body but rechargeable from outside, the tiny pacer would regulate the patient's heartbeat for decades without replacement, whereas the previous model required surgical replacement every two years. Space-derived automatic patient monitoring systems were being used in more and more hospitals. Tiny sensors on the patient's body would trigger an alarm when there was significant change in the patient's temperature or heartbeat or blood pressure or even in the oxygen-carbon dioxide levels in the blood, a signal of the onset of shock. For researchers living inside space simulators for long periods of time, the Ames Research Center developed an aspirin-sized transmitter pill. In general medical practice, the transmitter pill was swallowed by the patient; as it moved through the digestive system it radioed to the doctor diagnostic measurements of any of several kinds of deep-body conditions—temperatures, stomach acid levels, etc.

Energy: The nation's stepped-up program of energy research that began in 1973 found NASA with broad experience and an in-being program of research in devices that collect, store, transmit, and apply solar, nuclear, and chemical energy for production of mechanical and

electrical power. Solar cells had produced the electric power for several generations of spacecraft; when arrays of them were experimentally mounted on houses they supplied as much as three quarters of the energy needed to heat and cool the house. But solar cells were too expensive to be competitive with other systems; work was continuing on improving their efficiency and on new manufacturing techniques that would cut their cost in half. A long-standing problem with the efficient use of electrical energy has been the inability to store significant amounts of it for future use. NASA had done much work on developing more compact, higher-storage-capacity, longer life batteries. Nickel-cadmium batteries developed for the space program were already in general use; they could be recharged in 6 to 20 minutes instead of the 16 to 24 hours required for conventional batteries. Silver-zinc batteries used in spacecraft were too expensive for commercial use, but their unique separator material could double the capacity of conventional

This laminar flow clean room and special clothing are used at St. Luke's Hospital, Denver, Colo., to lower risk of infection in hip-joint replacements and other surgical procedures. Both the room and the clothing were based on space program experience and were developed under NASA contract by the Martin Marietta Corp.

nickel-zinc batteries. An extensive trial of this adaptation was begun with the fleet of Postal Service electric trucks. Batteries with 5 to 20 times the storage capacity of conventional mass-produced automobile batteries could have a wide range of uses: low-pollution automobile propulsion; storage of excess electrical power generated during low-demand daylight hours, and its release at times of peak demand, etc. Fuel cells had been developed by NASA to provide the longer duration Gemini and Apollo flights with electrical power; on Earth they could be used either for energy storage or energy conversion. One of the ingredients used in fuel cells was hydrogen; in this application hydrogen was broken down and combined with oxygen in a complex chemical process that produced water and electrical energy. But hydrogen is also a superb high-performance, low-pollutant fuel whose source is inexhaustible. Liquid hydrogen had propelled men to and from the Moon. With its years of work with hydrogen as a rocket fuel, NASA had more experience than anyone else in the production, transportation, storage, pumping, and use of hydrogen. One possible use of hydrogen was as compact, clean energy that could be transported into large urban areas. Many kinds of Earth-based power plants could burn hydrogen, alone or in various combinations, to produce energy with low pollution side effects.

APOLLO IMPACT

The creation of NASA's university and technology transfer programs in the early 1960s could be considered a side effect of Apollo. There were others. All lunar reconnaissance programs had been impacted by Apollo. The latter part of Ranger had been reoriented; Surveyor, the first lunar softlander, was reconfigured to support Apollo. If Surveyor worked, it would provide on-the-lunar-surface photography plus televised digging in the surface of the Moon for a better sense of soil composition. The remaining problem for Apollo was the need for detailed mapping photography of the Moon. So by the end of 1963 a third program was initiated—Lunar Orbiter, a state-of-the-art photographic mapping satellite that would go into orbit around the Moon and take mapping photographs of the portion of the Moon that featured potential landing zones for Apollo.

The vexing questions of rendezvous and extravehicular activity still had to be answered. So on 3 January 1962 NASA announced a new manned spaceflight project, Gemini. Using the basic configuration

of the Mercury capsule but scaling it up in size to hold a two-man crew, Gemini was to fit between Mercury and Apollo and provide early answers to assist the design work on Apollo. The launch vehicle would be the Titan II missile being developed by the Air Force. More powerful than Atlas and Titan I, it would have the thrust to put the larger spacecraft into Earth orbit. For a target vehicle that Gemini could rendezvous with, NASA chose the Air Force's Agena; launched by an Atlas, the second-stage Agena had a restartable engine that enabled it to have both passive and active roles. Gemini would be managed by the same Space Task Group that was operating Mercury; the project director would be James A. Chamberlin, an early advocate of an enlarged Mercury capsule.

Gemini began as a Mark II Mercury, a "quick and dirty" program. The only major engineering change aside from scale-up was to modularize the various electrical and control assemblies and place them outside the inner shell of the spacecraft to simplify and speed up maintenance. But perhaps not an engineer alive could have left it at that. After all, Gemini was supposed to bridge to Apollo, wasn't it? Here was a chance to try out ideas. If they worked, they would be available for Apollo. There was the paraglider, for example, that Francis Rogallo had been experimenting with at Langley. If that worked, Gemini could forget parachutes and water landings with half the Navy out there; with a paraglider Gemini could land routinely on land. And the spacecraft should be designed to have more aerodynamic lift than Mercury, so the pilot would have more landing control. And fuel cells instead of batteries; with enough electric power you could have longer duration flights. And fighter-plane-type ejection seats for crew abort, superseding the launch escape rocket that perched on top of Mercury.

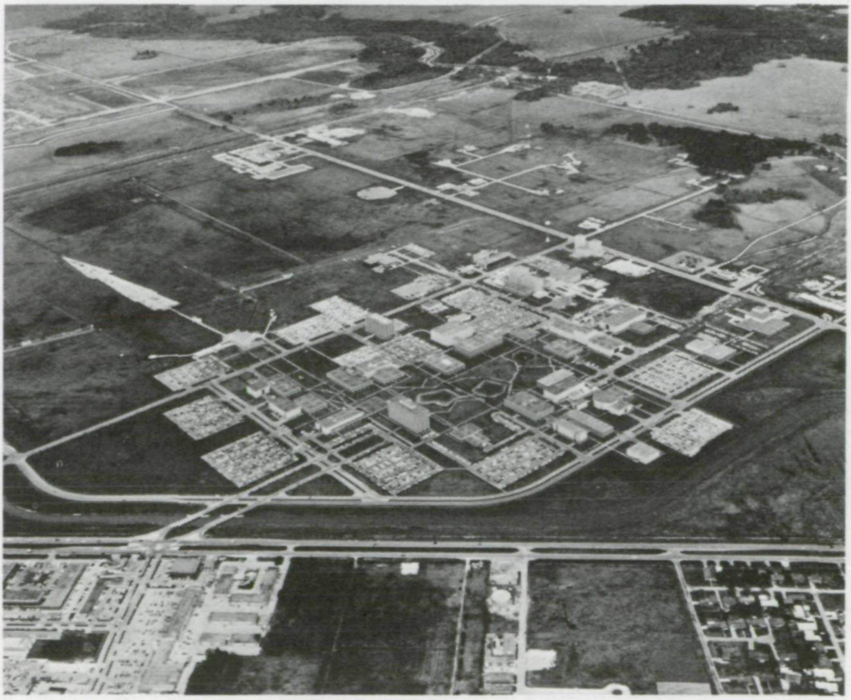
All these innovations were cranked into the program, and contracts and subcontracts were let for their design and fabrication. Soon the monthly bills for Gemini were running far beyond what had been budgeted. In every area, it seemed, there were costly problems. The paraglider and ejection seats wouldn't stabilize in flight; the fuel cell leaked; Titan II had longitudinal oscillations—the dreaded "pogo" effect—too severe for manned flights; Agena had reconfiguration problems. Cost overruns had become severe by late 1962; by March 1963 they were critical. The original program cost of $350 million had zoomed to over $1 billion—$200 million higher than the figures Associate Administrator Seamans had used in Congress a few days before! Charles W. Mathews, the new program manager, cracked down. Flight

schedules were stretched out; the paraglider gradually slid out of the program. By early 1964 most of the engineering problems were responding to treatment.

With the Mercury program, the spacecraft design role in Apollo, and now Gemini, it was clear that the Space Task Group needed a home of its own and some growing room. On 19 September 1961, Administrator Webb announced that a new Manned Spacecraft Center would be built on the outskirts of Houston, Texas. It would house the enlarged Space Task Group, now upgraded to a center, and would have operational control of all manned missions as well as be the developer of manned spacecraft. Water access to the Gulf of Mexico was provided by the ship canal from Houston to Galveston.

Water access played a role in all site selection for new Apollo facilities. The big Michoud Ordnance Plant outside New Orleans, where the 10-meter-diameter Saturn V first stage would be fabricated,

Manned Spacecraft Center, 1970. Renamed Johnson Space Center in 1973, this has been the lead center for the design and development of manned spacecraft and for the operational control of manned space flights.



Michoud Operations, 1965.

The Mississippi Test Facility headquarters building, 1966. It is now the National Space Technology Laboratories.

was on the Mississippi River; the Mississippi Test Facility, with its huge test stands for static firing tests of the booster stages, was just off the Gulf of Mexico, in Pearl River County, Mississippi.

All this effort would come together at the launch site at Cape Canaveral, Florida, where NASA had a small Launch Operations Center, headed by Kurt H. Debus. NASA had been a tenant there, using Air Force launch facilities and tracking range. Now Apollo loomed. Apollo would require physical facilities much too large to fit on the crowded Cape. For safety's sake there would have to be large buffer zones of land around the launch pads; if a catastrophic accident occurred, where all stages of the huge launch vehicle exploded at once, the force of the detonation would approach that of a small atomic bomb. So NASA sought and received congressional approval to purchase 450 square kilometers of Merritt Island, just northwest of the Air Force facilities. Lying between the Banana River and the Atlantic and populated mostly by orange growers, Merritt Island had the requisite water access and safety factors.

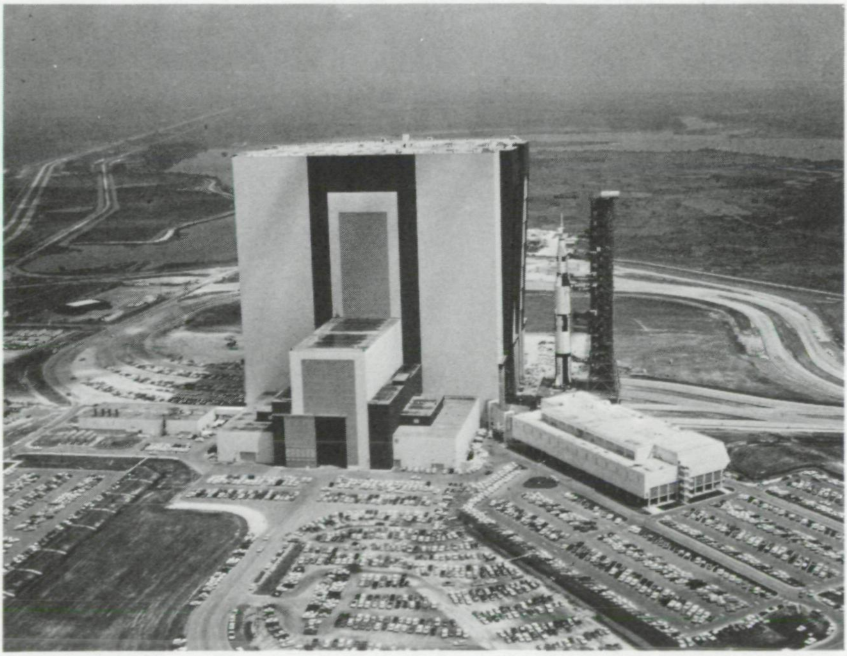
Planners struggled through 1961 with a wide range of concepts and possibilities for the best launch system for Apollo, hampered by having only a gross knowledge of how the vehicle would be configured, what the missions would involve, and how frequent the launches would be. Finally on 21 July 1962 NASA announced its choice: the Advanced Saturn (later Saturn V) launch vehicle would be transported to the new Launch Operations Center on Merritt Island stage by stage; the stages would be erected and checked out in an enormous Vertical Assembly Building; the vehicle would be transported to one of the four launch pads several miles away by a huge tractor crawler. This system was a major departure from previous practice at the Cape; launch vehicles had usually been erected on the launch pad and checked out there. Under the new concept the vehicle would be on the launch pad a much shorter time, allowing for a higher launch rate and better protection against damage from lightning, hurricanes, and weather contamination in general. As with the other new Apollo facilities, the Corps of Engineers would supervise the vast construction project.

The simultaneous building of facilities and hardware was going to take a great deal of money and a great many skilled people. The NASA budget, $966.7 million in Fiscal Year 1961, was $1.825 billion in FY 1962. It hit $3.674 billion the next year and by FY 1964 was $5.1 billion. It would remain near that level for three more years. In personnel, NASA grew in those same years from 17 471 to 35 860. And

of course this was small potatoes compared to the mushrooming contractor and university force where 90 percent of NASA's money was spent. When the Apollo production line peaked in 1967, more than 400 000 people were working on some aspect of Apollo.

Indeed, as the large bills began to come in, there was some wincing in the political system. President Kennedy wondered briefly if the goal was worth the cost; in 1963 Congress had its first real adversary debate on Apollo. Administrator Webb had to point out again and again that this was not a one-shot trip to the Moon but the building of a national space capability that would have many uses. He also needled congressmen with the fact that the Soviets were still ahead; in 1963 they were orbiting two-man spacecraft, flying a 208-kilometer-orbit tandem mission, and orbiting an unmanned prototype of a new spacecraft. Support rallied. The Senate rejected an amendment that would have cut the FY 1964 space budget by $500 million. The speech that President Kennedy was driving through Dallas to deliver on that fateful 22 Novem-

Kennedy Space Center, 1966. A 111-meter-tall Saturn V launch vehicle has emerged from the cavernous Vehicle Assembly Building on its 1820-metric-ton crawler and begun its stately processional to the launch complex five kilometers away.



ber 1963 would have defended the expenditures for the space program:

> This effort is expensive—but it pays its own way, for freedom and for America. . . . There is no longer any doubt about the strength and skill of American science, American industry, American education and the American free enterprise system. In short, our national space effort represents a great gain in, and a great resource of, our national strength.

PATH TO APOLLO

As 1963 drew to a close, NASA could feel that it was on top of its job. The master plan for Apollo was drawn; the organization and the key men were in place. Mercury had ended with L. Gordon Cooper's 22-orbit flight, far beyond the design limits of the spacecraft. For those Americans old enough to have thrilled to Lindbergh's historic transatlantic flight 36 years earlier, it was awesome that in only 50 minutes more flight time Cooper had flown 955 000 kilometers to Lindbergh's 5000. Of 13 NASA launches during the year, 11 were successful. In addition to improved performance from the established launch vehicles, Saturn I had another successful test flight, as did the troublesome Centaur. The *Syncom II* communications satellite achieved synchronous orbit and from that lofty perch transmitted voice and teletype communications between North America, South America, and Africa. The *Explorer XVIII* scientific satellite sailed out in a long elliptical orbit to measure radiation most of the way to the Moon.

III

Tortoise Becomes Hare

As 1964 dawned, the worst of Gemini's troubles were behind. The spacecraft for the first flight was already at the Kennedy Space Center (Launch Operations Center, renamed in November 1963 by President Lyndon B. Johnson), being minutely checked out for the flight. Too minutely, too time-consumingly. Not until 8 April did *Gemini I* lift off unmanned into an orbit which confirmed the launch vehicle-spacecraft combination in the rigors of launch. The excessive checkout time of *Gemini I* generated a new procedure. Beginning with the next spacecraft, a contingent from the launch crew would work at the factory (McDonnell Douglas in St. Louis, Missouri) to check out the spacecraft there. When it arrived at the Cape, it would be ready to be mated with its Titan II, have the pyrotechnics installed, and be launched. Only in this way could one hope to achieve the three-month launch cycle planned for Gemini.

The new system delayed the arrival of the second Gemini spacecraft at the Cape. There the curse set in. Once on the pad the spacecraft was struck by lightning, threatened by not one but two hurricanes, and forced to undergo check after check. And when launch day finally came in December, the engines ignited and then shut down. More rework. Finally on 19 January 1965, *Gemini II* rose from the launch pad on the tail of almost colorless flame from Titan II's hypergolic fuels, and in a 19-minute flight confirmed the readiness of a fully equipped Gemini spacecraft and the integrity of the heatshield during reentry. Gemini was man-rated.

The final test flight was to be a manned, three-orbit qualification flight. It was conducted on 23 March without incident. Now the diversified flight program could continue. One of the program objectives was to orbit men in space for at least the week that it would take an Apollo flight to go to the Moon, land, and return. *Gemini IV* (3–7 June)

stayed aloft four days; *Gemini V* (21–29 August) doubled it to eight days and surpassed the Soviet long-duration record; *Gemini VII* (4–18 December) provided the clincher with 14 days (330 hours 35 minutes). Of more lasting importance than the durability of the equipment was the encouraging medical news that no long-term harmful effects were found from extended exposure to weightlessness. There were temporary effects, of course: heartbeat slowed down, blood tended to pool in the legs, the bones lost calcium, etc., but these conditions tended to stabilize after a few days in weightlessness and to return to normal after a few days back on Earth. So far there seemed to be no physiological time limit for man living in space.

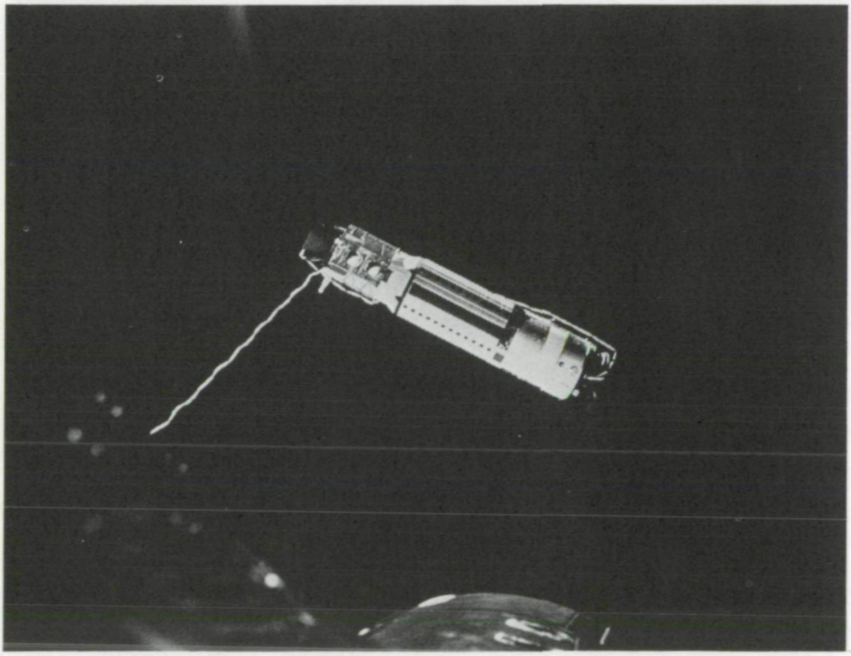
A crucial question for Apollo was whether the three rendezvous and docking maneuvers planned for every lunar flight were (a) possible and (b) feasible. *Gemini III* made the tentative beginning by testing the new thruster rockets with short-burst firings that changed the height and shape of orbit and one maneuver that for the first time shifted the plane of the flight path of a spacecraft. *Gemini IV* tried to rejoin its discarded second-stage booster but faulty techniques burned up too much maneuvering fuel and the pursuit had to be abandoned—a valuable lesson; back to the computers for better techniques! *Gemini V* tested out the techniques and verified the performance of the rendezvous radar and rendezvous display in the cockpit.

Then came what is still referred to by NASA control room people with pride but also with slight shudders as "Gemini 76." The original mission plan called for a target Agena stage to be placed in orbit and for Gemini to launch in pursuit of it. But the Agena fell short of orbit and splashed into the Atlantic. The Gemini spacecraft suddenly had no mission. Round-the-clock debate and recomputation produced a seemingly bizarre solution, which within three days of the Agena failure was approved by Administrator Webb and President Johnson: (a) remove the Gemini 6 spacecraft-launch vehicle combination intact from the launch pad and store it carefully to preserve the integrity of checkout; (b) erect Gemini 7 on the launch pad, check it out, and launch it; (c) bring Gemini 6 out and launch it to rendezvous with the long-duration Gemini 7. And it happened. *Gemini VII* was launched 4 December 1965; *Gemini VI* was back on the pad for launch by 12 December. On launch day the engines ignited, burned for four seconds, shut off automatically when a trouble light lit up. On top of the fueled booster Astronaut Walter M. Schirra, Jr., sat with his hand on the lanyard of the ejection seat while the control room checked out the condition of the

fueled booster. But the potential bomb did not explode. On 15 December *Gemini VI* lifted off to join its sister ship in orbit. On his fourth orbit Schirra caught up to *Gemini VII* and maneuvered to within 10 meters; in subsequent maneuvers he moved to within 30 centimeters. Rendezvous was feasible. Was docking?

On 16 March 1966, *Gemini VIII* on its third orbit docked with its Agena target. Docking too was feasible, though in this case not for long. Less than half an hour after docking for an intended full night in the docked position, the two spacecraft unaccountably began to spin, faster and faster. Astronaut Neil A. Armstrong could not stabilize the joined spacecraft, so he fired his Gemini thrusters to undock and maneuver away from the Agena. Still he could not control his single spacecraft with the thrusters; lives seemed in jeopardy. Finally he fired the reentry rockets, which did the job. By then ground control had figured out that one thruster had stuck in the firing position. Armstrong made an emergency landing off Okinawa. Despite hardware problems, docking had been established as feasible.

This photo looks out *Gemini XI's* window at the Agena rocket with which the Gemini crew is practicing rendezvous and tethered stationkeeping.



Rendezvous was new and difficult, so experimentation continued. *Gemini IX* (3–6 June 1966) tried three kinds of rendezvous maneuvers with a special target stage as its passive partner, but docking was not possible because the shroud covering the target's docking mechanism had not separated. The shroud did not prevent simulation of an Apollo lunar orbit rendezvous. *Gemini X* (18–21 July 1966) did dock with its Agena target and used the powerful Agena engine to soar to a height of 766 kilometers, the highest in space man had ventured. It rendezvoused with the derelict Agena left in orbit by *Gemini VIII* four months earlier, using only optical methods and thereby demonstrating the feasibility of rendezvous with passive satellites for purposes of repairing them. On the

America's first space walk. Astronaut Edward H. White II fired short bursts with his hand-held maneuvering gun to move around in the zero g of space before returning to the *Gemini IV* spacecraft.

next flight *Gemini XI* caught up with its target in its first orbit, demonstrating the possibility of quick rendezvous if necessary for rescue or other reasons. Each astronaut practiced docking twice. Using Agena propulsion, they rocketed out to 1372 kilometers above the Earth, another record. The final Gemini flight, *Gemini XII* (11 November 1966) rendezvoused with its target Agena on the third orbit and kept station with it.

Would astronauts be able to perform useful work outside their spacecraft when in orbit or on the Moon? This was the question extravehicular activity (EVA) was designed to answer. The answers proved to be various and more difficult than had been envisioned.

Gemini IV began EVA when Edward H. White II floated outside his spacecraft for 23 minutes. Protected by his spacesuit and attached to Gemini by an eight-meter umbilical cord, White used a hand-held maneuvering unit to move about, took photographs, and in general had such an exhilarating experience that he had to be ordered back into the spacecraft. Because he had no specific work tasks to perform, his EVA seemed deceptively easy.

That illusion was rudely shattered by the experience of *Gemini IX*, when Eugene A. Cernan spent two hours in EVA; he had tasks to perform in several areas on the spacecraft. His major assignment was to go behind the spacecraft into the adapter area, put on the 75-kilogram Astronaut Maneuvering Unit—a more powerful individual flight propulsion system the Air Force had built—and try it out. The effort to get the unit harnessed to his back was so intense that excessive perspiration within his spacesuit overtaxed the system and fogged his visor. The experiment was abandoned and he was ordered back into the spacecraft.

Much more pleasant was the experience of Michael Collins on *Gemini X*. He tried two kinds of EVA: the first time he stood in the open hatch for 45 minutes and made visual observations and took pictures; the second time he went out on a 10-meter tether, maneuvered for 55 minutes with the hand-held maneuvering unit and even propelled himself over to the station-keeping Agena and removed a micrometeoroid-impact experiment which had been in space for four months.

But reality raised its ugly head again during *Gemini XI* when Richard F. Gordon, Jr., was assigned a full schedule of work tasks along the spacecraft but had to terminate after 33 minutes because of fatigue. He had battled himself to exhaustion trying to control his bodily movements and fight against the opposite torque that any simple body motion set in train. It was Isaac Newton's Third Law of Motion in pure form.

NASA had learned its lesson. When *Gemini XII* went up, many additional body restraints and hand- and footholds had been added. Astronauts had trained for the strange floating sensation by doing the same assignments in water tanks on Earth. Results were gratifying; in a 2-hour 6-minute tethered EVA (aside from two standup EVAs) Edwin E. Aldrin, Jr., successfully performed 19 separate work tasks. Total EVA on this flight added up to 5 hours 28 minutes.

On the last seven flights, Gemini experimented with the aerodynamic lift of the spacecraft to ensure pinpoint landings on the Earth's surface; with the dispersions possible when Apollo came in from 370 000 kilometers away, tired astronauts would need this. The inertial guidance system provided inputs to the computer, which solved the guidance equations. On flights VI–X the reentry was controlled by the crew. On the last two flights the data were fed into the automatic system. Results were promising. The average navigational accuracy of the seven flights was within 3 kilometers of the aiming point, much better than previous flights.

Gemini was primarily a technological learning experience. So it is not surprising that of the 52 experiments in the program, more than half—27—were technological, exploring the limits of the equipment. But there were also 17 scientific experiments and 8 medical ones. An important one was the 1400 color photographs taken of Earth from various altitudes. This provided the investigators the first large corpus of color photographs from which to learn more about the planet we live on.

Probably the most valuable management payoff from Gemini was the operational one—how to live and maneuver in space; next was how to handle a variety of situations in space by exploiting the versatility and depth of the vast NASA-contractor team that stood by during flights. Finally there were valuable fiscal lessons: an advanced technology program had a "best path" between too slow and too fast. Deviation on either side, as had occurred in the early days of Gemini, could cost appalling amounts of money. But once on track, even economies were possible. Once Gemini flights were on track, for example, Associate Administrator for Manned Space Flight George E. Mueller (successor to Holmes) had won agreement from his principal contractors to cut the three-month period between launches to two months. This was primarily to get Gemini out of the way before Apollo launches started, but it paid off financially, too; where total program costs for Gemini were estimated in FY 1964 to be $1.350 billion, the actual cost closed out at $1.290 billion.

This, then, was Gemini—a versatile, flexible spacecraft system that wound up exploring many more nooks and crannies of this new arcane art of spaceflight than its originators ever foresaw—which is as it should be. Major lessons were transmitted to Apollo—rendezvous, yes; docking, yes; EVA, yes; manned flights up to two weeks in duration, yes. Equally important, there was now a big experience factor for the astronauts and for the people on the ground, in the control room, around the tracking network, on backup status in industry. The system had proved itself in the pit—it had evolved a total team that had solved real-time problems in space with men's lives at stake. This was no mean legacy to Apollo.

Some of the technological payoff had come too late. With the increasing sophistication of Gemini and the consequent slippage of both financial and engineering schedules, much of the day-to-day engineering could not be waited for by the Apollo designers and engineers. They had to invent their own wheel. But the state of the art had been advanced—thrusters, fuel cells, environmental control systems, space navigation, space suits, etc. In the development stage of Apollo the bank of knowledge from Gemini paid off in hundreds of subtle ways. The bridge had been built.

APOLLO REALIZED

Throughout the Gemini operational period, Apollo was slogging along toward completed stages and completed spacecraft. Saturn I, the booster almost overtaken by events, finished its ten-flight program in 1964 and 1965 with six launches featuring a liquid-hydrogen second stage. Not only was it proved out; the clustered-engine concept was demonstrated and an early form of Apollo guidance was tested. The last four flights were considered operational; one (SA–7, on 18 September 1964) tested a boilerplate Apollo spacecraft. The last three carried Pegasus meteoroid-detection satellites into orbit. The last two Saturn Is were fabricated entirely by industry, marking a transition from the Army-arsenal in-house concept that had previously characterized the Marshall Space Flight Center. Ten launches, ten successes.

Meanwhile the larger brother, the Saturn IB, was being born. Its first stage was to generate 7100 kilonewtons of thrust, from eight of the H–1 engines that had powered Atlas and Saturn I, but uprated to 890 kilonewtons each. The second stage was to feature the new J–2 liquid hydrogen engine, generating 890 kilonewtons of thrust. It was a crucial element of the forthcoming Saturn V vehicle, since in a five-

engine cluster it would power the second stage and a single J–2 would power the third stage.

Saturn IB was the first launch vehicle to be affected by a new concept—the "all-up" testing. Associate Administrator Mueller, pressed by budgetary constraints and relying on his industry experience in the Air Force's Minuteman ballistic missile program, pressed NASA to abandon its stage-by-stage testing. With intensive ground testing of components, he argued, NASA could with reasonable confidence test the entire stack of stages in flight from the beginning, at great savings to budget and schedule. Marshall engineers had built their splendid success record by being conservative; they vigorously opposed the new concept. But eventually Mueller triumphed. On 26 February 1966, the complete Saturn IB flew with the Apollo Command and Service Module spacecraft in suborbital flight; the payload was recovered in good condition. On 5 July the IB second stage, the Instrument Unit—which would house the electronic and guidance brains of the Saturn V—and the nose cone were propelled into orbit. The total payload was 28 332 kilograms, the heaviest the U.S. had yet orbited. On 26 August a suborbital launch qualified the Apollo Command Module for manned flight; the attached Service Module fired its engine four times; and an accelerated reentry trajectory tested the Apollo heatshield at the 40 000-kilometer-per-hour velocity of a spacecraft returning from lunar distance.

The largest brother, Saturn V, was still being pieced together. Developed by three different contractors, the three stages of Saturn V had individual histories and problems. The first stage, although the largest, had a long lead time and was on schedule. The third stage, though enlarged and sophisticated from the version flown on Saturn IB, had a previous history. It was the second stage that was the newest beast—five J–2 engines burning liquid hydrogen. It became the pacing item of the Saturn V and would remain so almost until the first launch.

Of the three spacecraft, the Lunar Module was, early and late, the problem child. For one thing, it was begun late—a whole year late. For another, it differed radically from previous spacecraft. There were two discrete spacecraft within the Lunar Module—one that would descend to the lunar surface from lunar orbit; another that would separate from the descent stage and leap off the lunar surface into lunar orbit and rendezvous with the mother Command Module. The engine for each stage would have to work perfectly for that one time it fired. Both had teething troubles. The descent engine was particularly troublesome, to the point that a second contract was let for a backup engine of different

design. Weight was a never-ending problem with the LM. Each small change in a system, each substitution of one material for another, had to be considered as much in terms of kilograms added or saved as any gain in system efficiency.

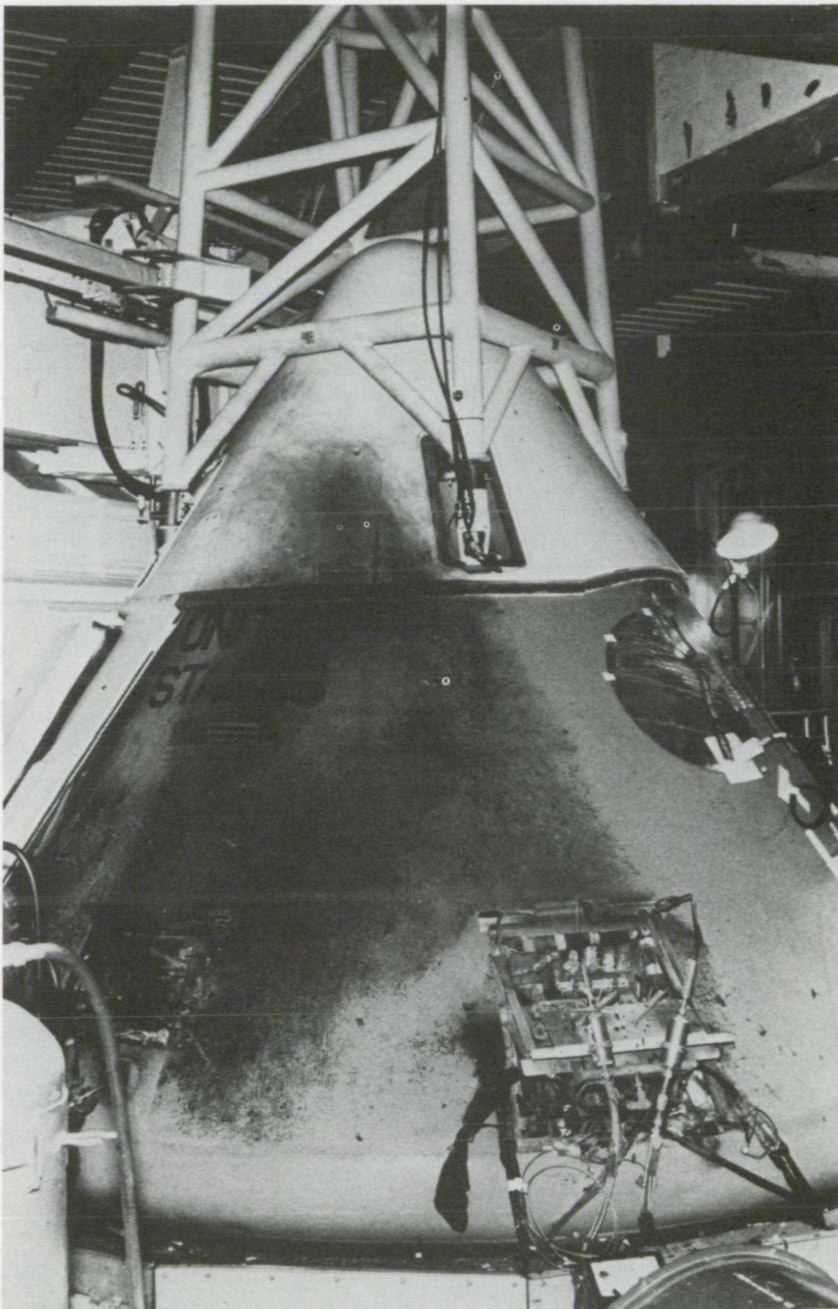
By the end of 1966, the Saturn IB and the Block I Apollo Command and Service Module were considered man-rated.

On 27 January 1967, AS-204, to be the first manned space flight, was on the launch pad at Cape Kennedy, moving through preflight tests. Astronauts Virgil I. Grissom, Edward H. White II, and Roger B. Chaffee were suited up in the Command Module, moving through the countdown toward a simulated launch. At T-minus-10 minutes tragedy struck without warning. As Maj. Gen. Samuel C. Phillips, Apollo Program Director, described it the next day: "The facts briefly are: at 6:31 p.m. (EST) the observers heard a report which originated from one of the crewmen that there was a fire aboard the spacecraft. . . ." Ground crew members saw a flash fire break through the spacecraft shell and envelop the spacecraft in smoke, Phillips said. Rescue attempts failed. It took a tortuous five minutes to get the spacecraft hatch open from the outside. Long before that the three astronauts were dead from asphyxiation. It was the first fatal accident in the American space program.

Shock swept across the nation and the world. In the White House, President Johnson had just presided over the signing of an international space law treaty when Administrator Webb phoned with the crushing news. Webb said the next day: "We've always known that something like this would happen sooner or later . . . who would have thought the first tragedy would be on the ground?"

Who, indeed? What had happened? How had it happened? Could it happen again? Was someone at fault? If so, who? There were many questions, few answers. The day following the fire, Deputy Administrator Seamans appointed an eight-member review board to investigate the accident. As chairman he chose Floyd L. Thompson, the veteran Director of the Langley Research Center. For months the Board probed the evidence, heard witnesses, studied documentation. On 10 April Webb, Seamans, Mueller, and Thompson briefed the House space committee on the findings: the fire had apparently been started by an electrical short circuit which ignited the oxygen-rich atmosphere and fed on combustible materials in the spacecraft. The precise wire at fault could probably never be determined. Like most accidents it should not have happened. There had been errors in design, faults in testing procedures. But the basic spacecraft design was sound. A thorough review of space-

The seared Apollo Command Module in which three astronauts lost their lives stands in mute desolation at Cape Kennedy.



craft design, wiring, combustible materials, test procedures, etc., was under way. Congress was not satisfied. Hearings in both Houses continued, gradually eroding Webb's support on Capitol Hill.

The Block I spacecraft would not be used for any manned flights. The hatch on the Block II spacecraft would be redesigned for quick opening. The hundreds of miles of wiring in the spacecraft were checked for fire-proofing, protection against damage, etc. An intensive materials research program devised substitute materials for combustible ones. In effect the Block II spacecraft was completely redesigned and rebuilt. The cost: 18 months delay in the manned flight schedule and at least $50 million. The gain: a sounder, safer spacecraft.

Well before men flew in Apollo spacecraft the question had been raised as to what, if anything, NASA proposed to do with men in space after Apollo was over. With the long lead times and heavy costs inherent in manned space programs, advance planning was essential. President Johnson proposed the question to Webb in a letter on 30 January 1964. NASA's first-look answer surfaced in congressional hearings on the FY 1965 budget. Funds were requested for study contracts that would investigate a variety of ideas for doing new things in space with the expensively acquired Apollo hardware. Possibilities: long-duration Earth-orbital operations; lunar surface exploration operating out of an unmanned Apollo Lunar Module landed on the Moon: long-duration lunar orbital missions to survey and map the Moon; Earth-orbital operations leading to space stations.

Through 1965 and 1966 the studies intensified and options were fleshed out. The Woods Hole conference in the summer of 1965 brought together a broad spectrum of the American science community and identified some 150 scientific experiments that were candidates for such missions. By 1966 there was a sense of urgency in NASA planning; the Apollo production line was peaking and would begin to decline in a year or two. Unless firm requirements for additional boosters, spacecraft, and other systems could be delineated and funded soon, the production lines would shut down and the hardwon Apollo skills dispersed. In the FY 1967 congressional hearings, NASA presented further details and fixed the next fiscal year as the latest that hardware commitments could be deferred if the Apollo production line was to be used.

NASA went into the FY 1968 budget cycle with a fairly ambitious Apollo Applications proposal. It asked for an FY 1968 appropriation of $626 million as the down payment on six Saturn IBs, six Saturn Vs, and eight Apollo spacecraft per year. The Bureau of the Budget

approved a budget request of $454 million. This cut the program by one third. Congress appropriated only $253 million, so by mid-1968 the plan was down to only two additional Saturn IBs and one Workshop, with it and its Apollo Telescope Mount being deferred to 1971.

Manned spaceflight, with its overwhelming priority, had had both direct and indirect impact on the NASA space science program. From 1958 to 1963, scientific satellites had made impressive discoveries: the Van Allen radiation belts, the Earth's magnetosphere, the existence of the solar wind. Much of the space science effort in the next four years was directed toward finding more detailed data on these extensive phenomena. The radiation belts were found to be indeed plural, with definite if shifting altitudes. The magnetosphere was found to have an elongated tail reaching out beyond the Moon and through which the Moon periodically passes. The solar wind was shown to vary greatly in intensity with solar activity.

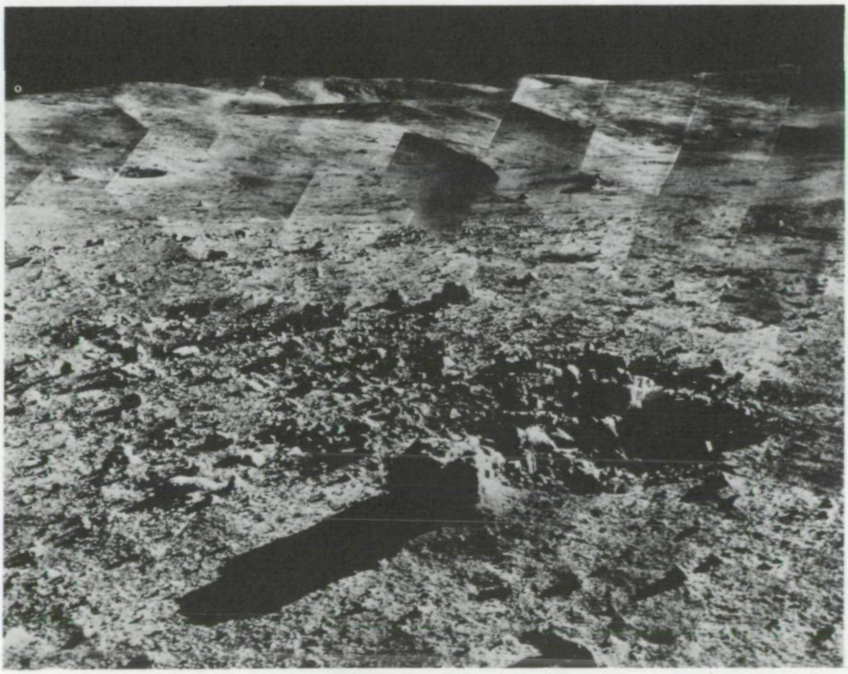
All of these were momentous discoveries about our nearby space environment. The first wave of discoveries said one thing to NASA: if you put up bigger, more sophisticated, more versatile satellites than those of the first generation, you will find many other unsuspected phenomena that might help unravel the mysteries of the history of the solar system, the universe, and the cosmic mystery of how it all works. So a second generation of spacecraft was planned and developed; they were of the so-called observatory class—five to ten times as heavy as early satellites, built around a standard bus instrumented for a specific scientific discipline, but designed to support up to 20 discrete experimental instruments that could be varied from one flight to the next—solar observatories, astronomical observatories, geophysicial observatories. As these complex spacecraft were developed and launched in the mid-1960s, the first results were on the whole disappointing. The promise was confirmed by fleeting results but their very complexity inflicted them with short lifetimes and electrical failures. There were solid expectations that these could be worked out for subsequent launches. But by the late 1960s the impingement of manned spaceflight budgets on space science budgets reduced or eliminated many of these promising starts. Smaller satellites, such as the Pioneer series, survived and made valuable observations on the solar effects—measuring the solar wind, solar plasma tongues, and the interplanetary magnetic field.

Lunar programs fared somewhat better but did not come away unscathed. The lunar missions were now in support of Apollo, so they were allowed to run their course. Surveyor softlanded six out of its

seven spacecraft on the Moon from 1966 through 1968. Its television cameras gave Earthlings their first limited previews of ghostly lunar landscapes seen from the surface level. Its instruments showed that lunar soil was the consistency of Earth's wet sand, firm enough to support lunar landings by the LM. Lunar Orbiter put mapping cameras in orbit around the Moon in all of its five missions, photographed over 90 percent of the lunar surface—including the invisible back side—and surveyed potential Apollo landing sites.

Planetary programs suffered heavy cuts. The Mariner series was cut back, but its two flights were exciting new glimpses into the history of the solar system. *Mariner IV* flew past Mars on 14 July 1965 and gave man his first close-up view of Earth's fabled neighbor. At first glance the view was disappointing. Mars was battered by meteor impacts almost as much as the Moon. While there were no magnetic fields or radiation belts, there was a thin atmosphere. *Mariner V* flew

Surveyor VII, perched on the lunar surface in the highlands about 29 kilometers north of the big crater Tycho, took the photographs in this panoramic mosaic of the area around its landing site. In the center of the picture the rolling horizon is about 13 kilometers distant; the 1.5-meter crater in the foreground is about 5 meters away.



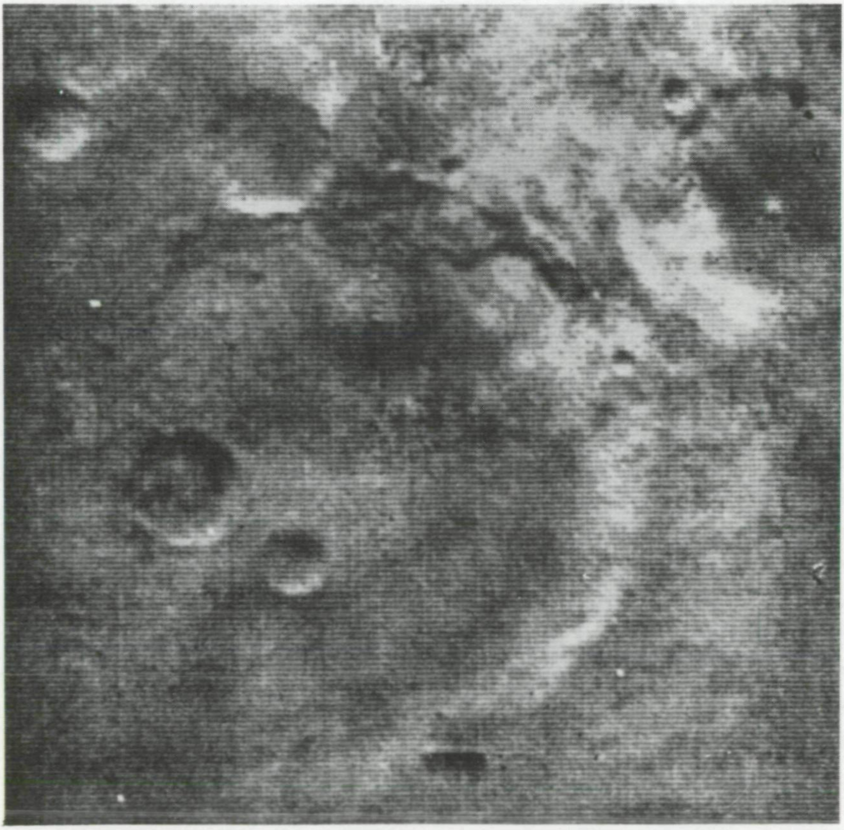
past Venus on 19 October 1967; this second pass at mysterious Venus found no magnetic field but an ionosphere that deflected the solar wind. The atmosphere was dense and very hot; temperatures were recorded as high as 700 K, with 80 percent of the atmosphere being carbon dioxide. But the immediate future of more sophisticated planetary exploration seemed bleak. The ambitious Voyager program was curtailed in FY 1966, finally dropped in FY 1968; it envisioned large planetary spacecraft launched on Saturn V which would deploy Mars entry capsules weighing 2270 to 3180 kilograms.

The applications satellites had been a crowning achievement for NASA in the early 1960s. The NASA policy of bringing a satellite system along through the research and development stages to flight demonstration of the system and then turning it over to someone else to convert into an operational system received its acid test in 1962. With the demonstration of Syncom performance, the commercial potential of communications satellites became obvious and immediate. NASA's

***Lunar Orbiter II* appears in this telephoto shot to be inside the huge lunar crater Copernicus. The mountains in the center of the crater rise 300 meters above the flat floor, as does the rim. Distance across this part of the crater is about 27 kilometers.**

R&D role seemed over, but how should the valuable potential be transferred to private ownership without favoritism? The Kennedy Administration's answer was the Communications Satellite Corporation, a unique concept of a government-industry-international combination. The board of directors would be made up of six named by the communications industry, six by public stockholders, and three named by the President. The corporation would be empowered to invite other nations to share the investment, the services, and the profits. This precedent-setting proposal stirred strong political emotions, especially in the Senate. A 20-day debate ensued—even escalating to filibuster, the time-honored last resort in cases of deeply devisive issues—before the Administration proposal was approved. On 31 August 1962,

***Mariner IV*, at a slant range of 1250 kilometers, took this photo of Mare Cimmerium on Mars. With craters pockmarked by newer craters, Mars looked depressingly like the Moon.**



President Kennedy signed the bill into law. ComSatCorp, as it came to be called, set up in business. On 6 April 1965, its first satellite, *Early Bird I,* was launched into synchronous orbit by NASA on a reimbursable basis. By the end of 1968, there was an Intelsat network of five communications satellites in synchronous orbits, some 20 of an expected 40 ground stations in operation, and 48 member nations participating. The Soviets had mounted a competitive system of Molniya satellites with a first launch in 1965. They too had sought international partnership, but only France outside of the Iron Curtain countries signed up. By 1968 they had launched 10 Molniya satellites into their standard elliptical orbit. On the American side, the question of government-sponsored research on communications satellites was not completely solved by the creation of ComSatCorp. Congress continued to worry over the thorny question of whether the government should carry on advanced research on communications satellites versus the prospect that a government-sponsored monopoly would profit from the results.

Weather satellites were simpler in the sense that the relationship was confined to two government agencies. The highly successful Tiros was seized on by the Weather Bureau as the model for its operational satellite series. NASA had high hopes for its follow-on Nimbus satellite, bigger, with more experiments measuring more parameters. The Weather Bureau, however, felt that unless NASA could guarantee a long operational lifetime for Nimbus, it was too expensive for routine use. So NASA continued Nimbus as a test bed for advanced sensors that could provide better measurements of the vertical structure of the atmosphere and global collection of weather date.

Navigational satellites, one of the early bright possibilities of space, continued to be intractable. But there was a new entry—the Earth resources satellite. Impressed by the Tiros photographs and even more by the Gemini photographs, the Department of Interior suggested an Earth resources satellite program in 1966. Early NASA investigation envisioned a small, low-altitude satellite in Sun-synchronous orbit. What could be effectively measured with existing sensors, to what degree, with what frequency, in what priority? These questions involved an increasing number of government agencies. Then there was the complex question of what trade-off was best between aircraft-borne sensors and satellite-borne ones. It was a new kind of program for NASA, involving many more government agencies and many more political sensitivities than the uncluttered researches in space.

The advanced research activities of NASA also became more

subtle and difficult to track. An interlocking network of basic research and applied research, advanced research was designed to feed new ideas and options into the planning process. The most visible portion was flight research. The X-15 had culminated the series of Air Force/NASA research aircraft with a glittering series of speed and altitude records and a very solid base of aerodynamic data. The prototype B-70 had been turned over to NASA for research in large aircraft flying at supersonic speeds.

When the political question arose as to whether the United States should enter the international competition for a supersonic commercial transport aircraft—a sweepstakes already entered by Great Britain and France with their joint entry, the Concorde, and by the Soviet Union with its TU-144—NASA already had a solid data base to contribute. It also had the laboratories and the contracting base to manage the program. But wise counsel from Deputy Administrator Dryden led to NASA's retreat into a supportive R&D role; he argued that with Apollo under way, NASA could not politically sponsor two high-technology, enormously expensive programs in the same budget years without one of them being sacrificed to the other or killing each other off in competition for funds. The subsequent history of the supersonic transport program, including its eventual demise, was eloquent testimonial to the wisdom of his judgment. His death in December 1965 was a loss to the nation.

Another visible area of advanced research was the study of hydroplaning—the dangerous tendency of aircraft, when landing, to lose braking control on wet or slushy runways. Research done at Langley indicated that the wheels tended to float on top of the water surface; grooving the concrete would drain water and provide much greater traction. Quickly and successfully applied to runways, the same technique soon spread to the national highway system, with equally good results.

Other research efforts paid big dividends within the space program. Lewis Research Center had become involved in the use of liquid hydrogen as a rocket fuel in 1955. Although liquid hydrogen offered very attractive increases in thrust per kilogram as compared to previous fuels, hydrogen had a bad reputation left over from dirigible days and the *Hindenburg* disaster. But by 1957 Lewis was successfully and routinely firing an 89-kilonewton-thrust engine using liquid hydrogen as fuel. It was these tests that gave NASA the confidence in 1959 to decide that the upper stages of the lunar rocket should be fueled with

liquid hydrogen. Without this additional rocket power, it might have been impossible—or at least much more expensive—to put men on the Moon.

The quiet-engine program for commercial aircraft grew out of widespread public protest against noise levels around city airports. Again Lewis was the lead center; laborious research into all aspects of the jet engine—air inlets, turbine blades, exhaust characteristics—led to new possibilities that in combination would dramatically lower the level of noise generated by jet aircraft.

Long-range prospects of manned planetary exploration depended heavily on more efficient thrust-per-pound-of-fuel propulsion. To this end NASA had continued the long-range program inherited from the Air Force to develop a nuclear-propelled upper stage for a rocket. Engineering down to a compact package the enormous weight, size, and shielding of the kind of reactor used in nuclear electric power plants was a severe challenge. The inevitable intensification of radiation density and temperatures defeated existing materials that would contain and transmit the heat to an engine. Time after time over the years, test firings of promising configurations had to be stopped prematurely when radiation corrosion took its toll. Finally in December 1967 the NRX-A6 reactor ran for one hour at full power, twice the time achieved before. Improvements in reactor fuel elements cut radiation control in half. The Snap program of radioisotope thermoelectric generators also progressed. The Snap-27 had been selected to be the long-life power source for the Apollo science experiments to be left on the lunar surface.

The flight-test program on lifting body shapes for possible reentry configurations of future manned spacecraft got under way at Flight Research Center in 1964. The M-2 lifting body designed at Ames Research Center made 100 flights. Results indicated that a man could reenter the atmosphere and land safely on a runway in a lightweight lifting-body aircraft. Encouraged by the basic data, NASA ordered two more lifting bodies with different configurations—the M-2/F-2 and the HL-10. The M-2/F-2 made 15 successful flights in 1966-1967. The HL-10, after modification, made 13 flights in 1968, 3 of them rocket powered.

Although the tragic fire of January 1967 delayed plans for manned spaceflight in Apollo hardware for something like 18 months, the versatility of the system came to the rescue. The burden of checking out the major components of the system was quickly shifted to unmanned flights while a quick-opening hatch was designed and tested,

combustibles were sought out and replaced, and the wiring design was completely reworked. After a nine-month delay, flight tests resumed. On 9 November 1967, *Apollo 4* became the first unmanned launch of the awesome Saturn V. A 110-meter-high stack of three-stage launch vehicle and spacecraft, weighing a total of 2 823 891 kilograms, slowly

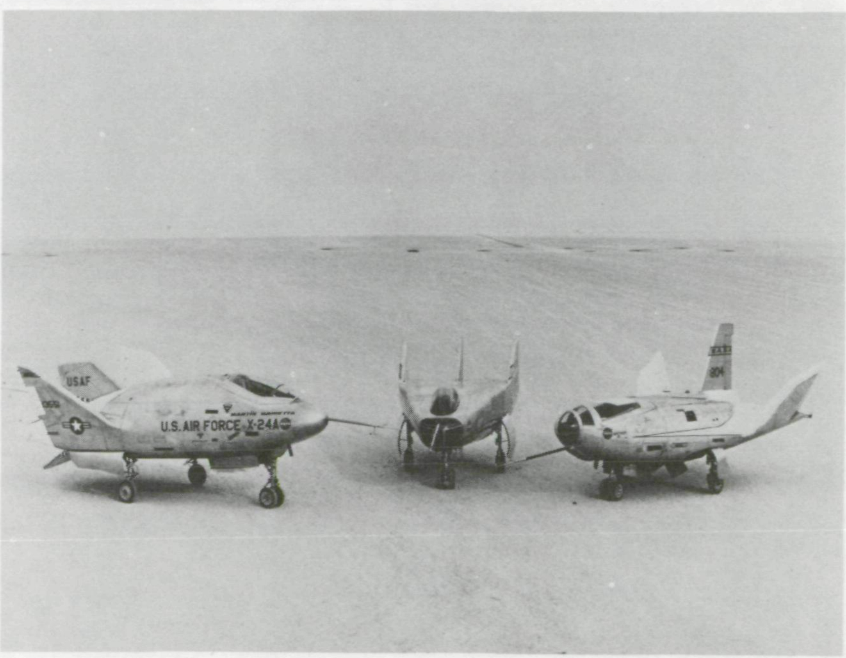
On 3 February 1966 the AEC-NASA Nuclear Rocket Development Station at Jackass Flats, Nev., fired the first complete "breadboard" nuclear rocket engine to be tested by the United States. It made two successful 15-minute test runs that day at partial power.

lifted off Launch Complex 39, propelled by a first-stage thrust of 33 800 kilonewtons. A record 126 529 kilograms of payload and upper stage were put into Earth orbit. After coast in Earth orbit, the third stage fired to simulate lunar trajectory, lifting the spacecraft combination to 17 335 kilometers. With the third stage discarded, the Service Module fired its engine to raise the apogee to 18 204 kilometers, then burned again to propel the spacecraft toward Earth reentry at the 40 000-kilometer-per-hour return speed from the Moon. All systems performed well; the third stage could restart in the vacuum of space; the automated Launch Complex 39 functioned beautifully. The once-controversial concept of "all-up" testing had been vindicated.

Next came the unmanned flight test of the laggard Lunar Module. On 22 January 1968, a Saturn IB launched a 14 392-kilogram Lunar Module into Earth orbit. It separated, tested its ascent and descent engines. The Lunar Module passed its first flight test.

Now to man-rate the huge Saturn V. *Apollo 6,* on 4 April 1968, put the launch vehicle through its paces—the stages, the guidance system, the electrical systems. Four of five test objectives were met;

Three lifting body configurations grouped on the dry lake bed at Flight Research Center–left to right, the X-24, M-2, and HL-10.



Saturn V was man-rated. The stage was set for the first manned spaceflight in Apollo since the tragic fire. Apollo 7 would test the crew and Command Module for the ten days in space that would later be needed to fly to the Moon, land, and return.

But beyond Apollo 7, the schedule was in real difficulty. It was the summer of 1968; only a year and a half remained of the decade within which this nation had committed itself to land men on the Moon. Somehow the flight schedule ought to be accelerated. Gemini's answer had been to launch missions closer together, but the size and complexity of Apollo hardware severely limited that option. The only other possibility was to get more done on each flight. For a time, however, it seemed that the next flight, Apollo 8, would accomplish even less than had been planned. It had been scheduled as the first manned test of the Lunar Module in Earth orbit, but the LM had a lengthy test-and-fix roadblock ahead of it and could not be ready before the end of the year, and perhaps not then. So a repeat of Apollo 7 was considered—another test of the Command Module in Earth orbit without the tardy LM but this time on the giant Saturn V. Eight years earlier that would have been considered a big bite; now, was it big enough, given Apollo's gargantuan task?

In Houston, George Low didn't think it was. After all, he reasoned, even this test-flight hardware was built to go to the Moon; why not use it that way? The advantages of early experience at lunar distances would be enormous. On 9 August he broached the idea to Gilruth, who was enthusiastic. Within days the senior managers of the program had been polled and had checked for problems that might inhibit a circumlunar flight. All problems proved to be fixable, assuming that Apollo 7 went well. The trick then became to build enough flexibility into the Apollo 8 mission so that it could go either way—Earth-orbital or lunar-orbital.

Apollo 7 was launched on 11 October 1968. A Saturn IB put three astronauts into Earth orbit, where they stayed for eleven days, testing particularly the Command Module—environmental system, fuel cells, communications. All came through with flying colors. On 12 November, NASA announced that Apollo 8 had been reconfigured to focus on lunar orbit. It was a bold jump.

On 21 December a Saturn V lifted the manned *Apollo 8* off Launch Complex 39 at the Cape. The familiar phases were repeated—Earth orbit, circularizing of the orbit, etc. But then the Saturn third stage fired again and added the speed necessary for the spacecraft to

As *Apollo 8* came around the backside of the Moon after going into lunar orbit, the crew was greeted with this haunting view of the Earth rising above the desolate lunar horizon.

escape Earth's gravity on a trajectory to the Moon. All the rehearsed or simulated steps went well. On 23 December the three-man crew became the first human beings to pass out of Earth's gravitational control and into the control of another body in the solar system. No longer was man shackled to the near environs of Earth. The TV camera looked back at a small, round, rapidly receding ball, warmly laced with a mix of blue oceans, brown continents, and white clouds that was startling against the blackness of space.

On Christmas Eve *Apollo 8* disappeared behind the Moon and out of radio communication with Earth. Not only were the astronauts the first humans to see the mysterious back side of the Moon; while there they had to fire their Service Module engine to reduce their speed enough to be captured into lunar orbit—irrevocably, unless the engine would restart later and boost them back toward Earth.

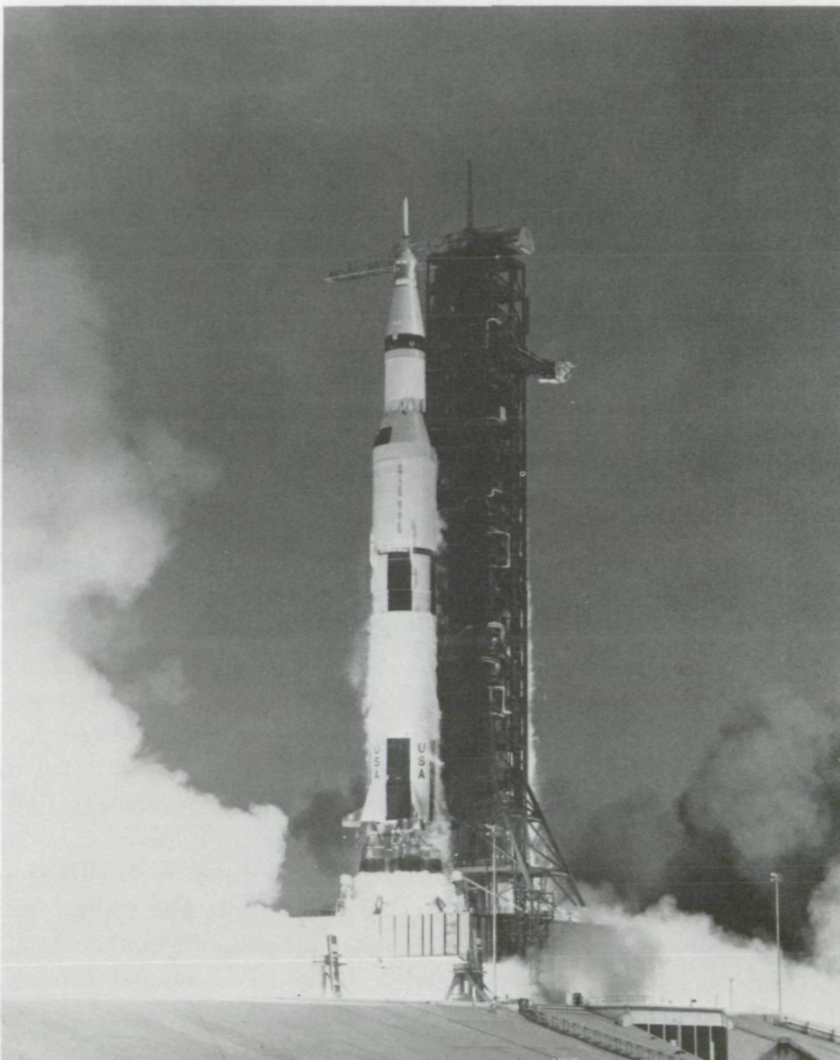
Another engine burn regularized their lunar orbit at 113 kilometers above the lunar surface. TV shared the breathtaking bird's-eye view of the battered lunar landscape with hundreds of millions on Earth. On Christmas Eve the crew read the creation story from Genesis and wished their viewers a Merry Christmas. On Christmas Day they fired their Service Module engine once again, acquired the 1000-meter-per-second additional speed they needed to escape lunar gravity, and triumphantly headed back to Earth. They had at close range verified the lunar landing sites as feasible and proved out the hardware and communications at lunar distance—except for the all-important last link, the Lunar Module.

That last link, the Lunar Module, was still of major concern to NASA. Two more flights were expended to confirm its readiness for lunar landing. The *Apollo 9* flight (3–13 March 1969) was the first manned test of the Lunar Module. The big Saturn V boosted the spacecraft combination into Earth orbit. The lunar-flight drill was carefully rehearsed; the Command and Service Modules separated from the third stage of the Saturn V, turned around and docked with the Lunar Module. The Lunar Module fired up and moved away to 183 kilometers; then the spacecraft rendezvoused and docked.

A final test—was anything different at lunar distance? On 18 May 1969, *Apollo 10* took off on a Saturn V to find out. The entire lunar landing combination blasted out to lunar distance. Once in lunar orbit, the crew separated the Lunar Module from the Command Module, descended to within 14 kilometers of the surface, fired the ascent system, and docked with the Command Module. Now all systems were "go."

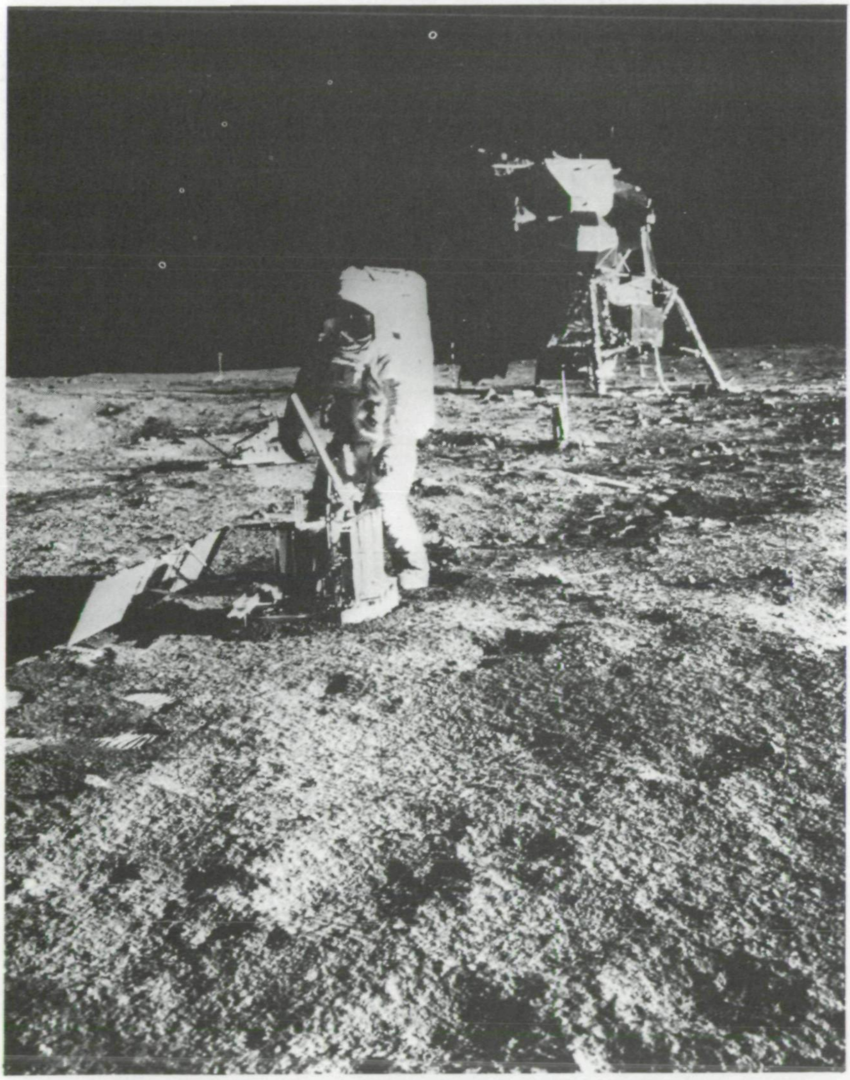
On 16 July 1969, *Apollo 11* lifted off for the ultimate mission of Apollo. Saturn V performed beautifully. The spacecraft combination got off to the Moon. Once in lunar orbit, the crew checked out their precarious second home, the Lunar Module. On 20 July the LM separated and descended to the lunar surface. At 4:18 p.m. (EST)

Apollo 11 **slowly rose off the launch pad at Kennedy Space Center on 16 July 1969, as the Saturn V thundered aloft on the way to landing the first men on the surface of the Moon.**



came the word from Astronuat Neil A. Armstrong: "Houston—Tranquility Base here—the Eagle has landed." After checkout, Armstrong set foot on the lunar surface—"one small step for a man—one giant leap for mankind." The eight-year national commitment had been fulfilled; man was on the Moon. Armstrong set up the TV camera

Astronaut Neil A. Armstrong took this photograph of Edwin E. Aldrin, Jr., deploying the passive seismic experiments at Tranquility Base, while the ungainly Lunar Module crouches in the background.



and watched his fellow astronaut Edwin E. Aldrin, Jr., join him on the lunar surface, as Michael Collins circled the Moon in the *Columbia* Command Module overhead. More than one fifth of the Earth's population watched ghostly TV pictures of two space-suited men plodding around gingerly in a ghostly, unlikely world of grey surface, boulders, and rounded hills in the background. The astronauts implanted the U.S. flag, deployed the scientific experiments to be left on the Moon, collected their rock samples, and clambered back into the Lunar Module. The next day they blasted off in the ascent module and rendezvoused with the Command Module.

The astronauts returned to an ecstatic reception. For a brief moment, man's day-to-day divisions had been suspended; the world watched and took joint pride in man's latest achievement in exploration. Astronauts and their families made a triumphant world tour which restated mankind's pride in this new plateau of man's conquest of the cosmos.

IV

Exploitation of Apollo

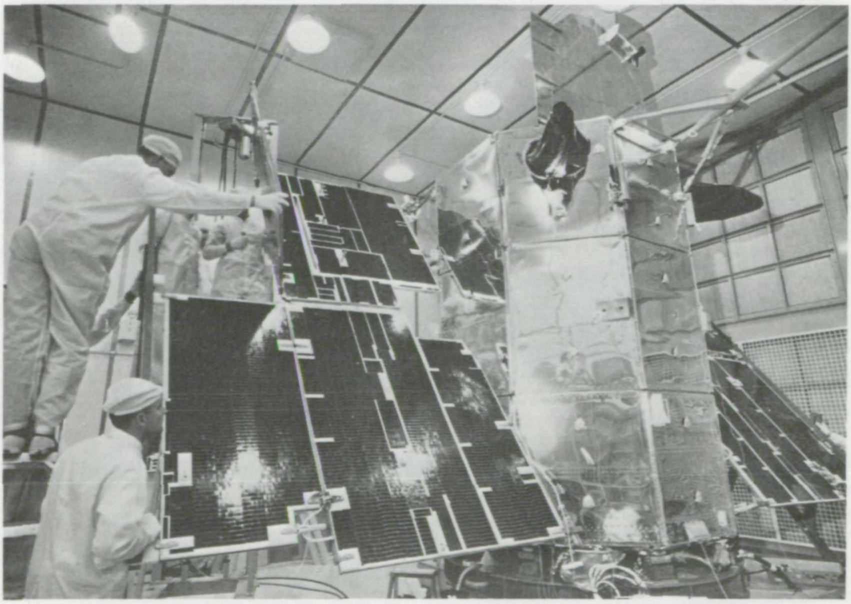
The worldwide euphoria over mankind's greatest voyage of exploration did not rescue the NASA budget. At its moment of greatest triumph, the space program was being drastically cut back from the $5-billion budgets that had characterized the mid-1960s. Part of the reduction was expected; the peak of Apollo production-line expenses was past. But the depth of the cut stemmed from emotional changes in the political climate, mostly centering on the unpopular Vietnam war—its sapping expenses in lives and money, the debilitating protests at home. As Congress read the public pulse, the cosmos could wait; the Soviet threat had for the moment been put to rest; the new political reality lay in domestic problems. The fiscal year 1970 budget was reduced to $3.7 billion. Something had to give. The basic Apollo mission was continued, but the last three flights had to be deleted. Space science projections were hit hard. The ambitious $2-billion Voyager program for planetary exploration dwindled into oblivion; it would later resurface as the much more modest Viking. The new Electronics Research Center in Cambridge, Massachusetts, under construction since 1964, was sacrificed—transferred to the Department of Transportation intact, a $40-million facility and 399 of 745 skilled employees.

But the bought-and-paid-for projects continued to earn dividends. An Orbiting Astronomical Observatory (*OAO 2*) was launched 7 December 1968. It was the heaviest and most complex automated spacecraft yet in the space science program. It took the first ultraviolet photographs of the stars. The results were portentous—first hard evidence of the existence of "black holes" in space. *Mariner 6* and *7*, launched in early 1969, journeyed to Mars, flew past as close as 3200 kilometers, took 198 high-quality TV photos of the planet, 2000 ultraviolet spectra, and 400 infrared spectra of the atmosphere and surface.

Other programs continued with prepaid momentum. The fifth and sixth Orbiting Solar Observatories were launched in 1969, as was the sixth Orbiting Geophysical Observatory. The supercritical wing, product of four years of wind-tunnel research by Richard T. Whitcomb at Langley, was committed to fabrication for test in flight at Flight Research Center. These flight tests confirmed the theoretical data; the current generation of transport aircraft could fly up to 160 kilometers per hour faster, promising significant operating economies.

1970 saw the launch of *Uhuru,* which scanned 95 percent of the celestial sphere for sources of X-rays. It discovered three new pulsar stars in addition to the one previously identified. In 1971 *Mariner 9* was launched; on 10 November, the first American spacecraft went into orbit around another planet. The early months in orbit were discouraging; a gigantic dust storm covered most of the Martian surface for two months. But the dust storm gradually cleared; photographs in 1972 showed startling detail. Mapping 85 percent of the Martian surface, *Mariner 9* photographs depicted higher mountains and deeper

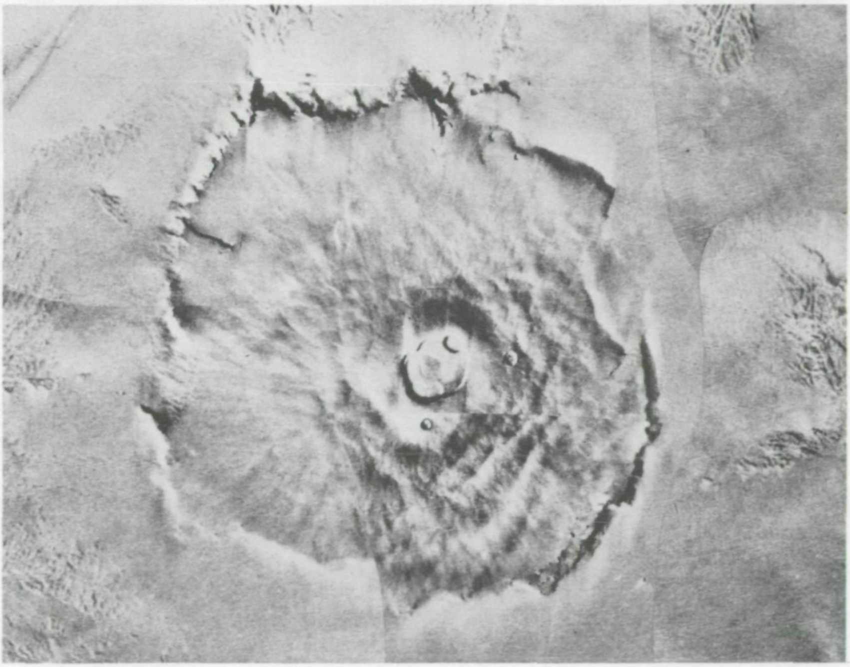
***OAO II,* the orbiting astronomical observatory, was the largest, heaviest, and most complex scientific spacecraft NASA had developed. With its solar panels deployed, as shown here, *OAO II* was 6.4 meters wide, weighed 2000 kilograms, and carried 11 ultraviolet telescopes into space.**



valleys than any on Earth. The rocky Martian moons, Deimos and Phobos, were also photographed. *OSO 7*, launched on 29 September 1971, was the first satellite to catch on film the beginning of a solar flare and the consequent solar streamers of hot gases that extended out 10.6 million kilometers; it would also discover "polar ice caps" on the Sun—dark areas several million degrees cooler than the normal surface temperatures. With the confirmation of the black holes—the enigmatic collapsed star remnants so dense in mass and gravity that even light cannot escape—and the previous discoveries of quasars and pulsars, these findings added up to the most exciting decade in modern astronomy.

Planetary exploration opened further vistas of other worlds. *Pioneer 10*, launched 2 March 1972, left the vicinity of Earth at the highest velocity ever achieved by a spacecraft (51 200 kilometers per hour) and took off on an epic voyage to the huge, misty planet Jupiter. Giant of the solar system, swathed with clouds, encircled by a cluster

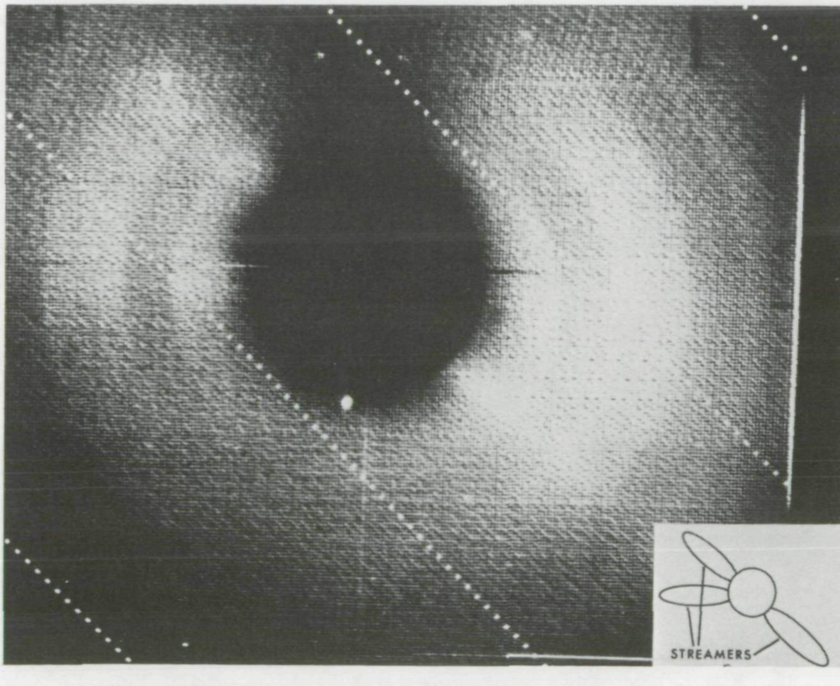
As the great dust storm on Mars cleared, the circling *Mariner 9* photographed this giant mountain. Some 500 kilometers across at the base and rising to a height estimated to be 25 kilometers, Olympus Mons dwarfs any mountain on Earth.



of moons, Jupiter was an inescapable target if one hoped to understand the composition of the solar system. Out from the Sun, out from Earth, *Pioneer 10* ventured for a year and a half—through the unexplored Asteroid Belt and far beyond. After a 992-million-kilometer journey, on 3 December 1973 the tiny spacecraft flew past Jupiter. It survived the fierce magnetic field and sent back photographs of the huge planet and several of its moons, measured temperatures and radiation and the magnetic field. Steadily sailing past Jupiter and away from the Sun, in 1987 *Pioneer 10* would cross the orbit of Pluto, becoming the first man-made object to travel out of our solar system and into the limitless reaches of interstellar space.

Pioneer 10's partner, *Pioneer 11,* took off on 5 April 1973 to follow the same outward path. On 3 December 1974 it passed Jupiter at the perilously close distance of 42 000 kilometers—as opposed to 129 000 kilometers for *Pioneer 10*—and returned data. The composite

***OSO 7*'s White Light Coronography showed three coronal streamers shooting out from the Sun. The instrument produces an artificial eclipse (the black circle in the center) and photographs coronal activity. Distance from the center to the edge of the photograph is about 6.5 million kilometers.**

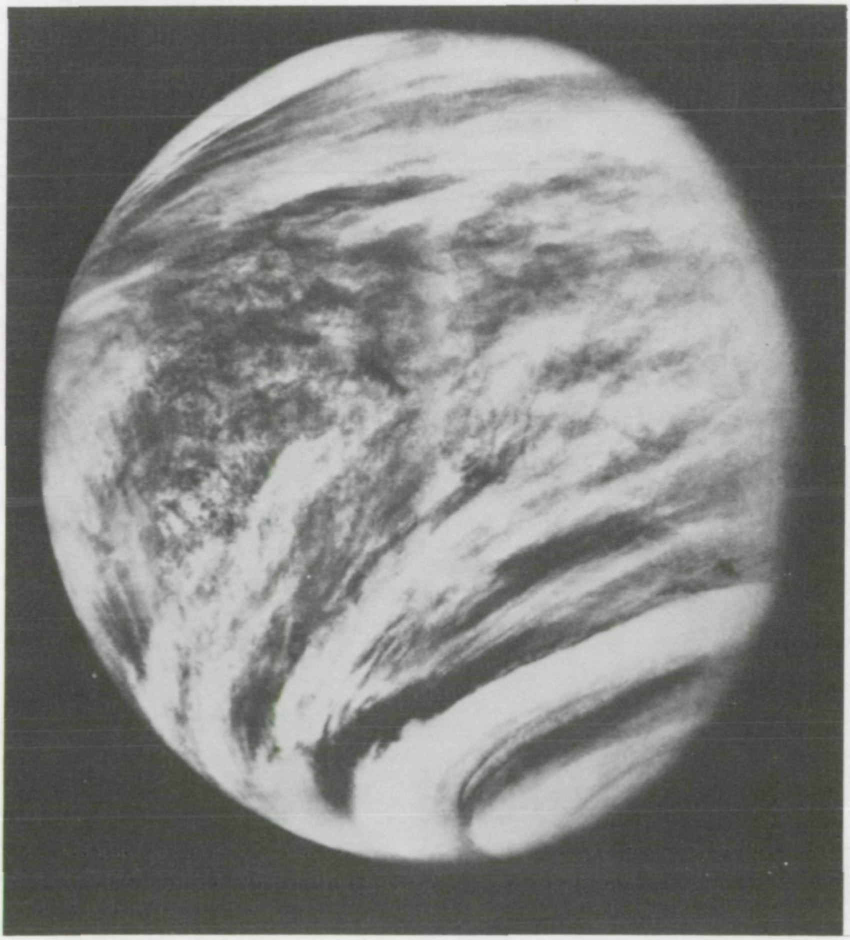


picture from the reports of the two spacecraft depicted an enormous ball of hydrogen, with no fixed surface, emitting much more radiation than it received from the Sun, shrouded with a turbulent atmosphere in which massive storms such as the Great Red Spot (40 000 kilometers in length) had raged for at least the 400 years since Galileo first trained a telescope at Jupiter. *Pioneer 11* swung around the planet and, taking advantage of Jupiter's gravitational field, accelerated outward at 106 000 kilometers per hour toward the distant planet Saturn, where in 1979 (if things went well) it would observe at close range this lightest of the planets—it could float on water—its mysterious rings, and its 4800-kilometer-diameter moon Titan, which might be capable of sustaining life.

Jupiter, as photographed by *Pioneer 10* from 2.5 million kilometers out. The large black oval to the left is the famous Great Red Spot, an enormous storm that has raged for at least hundreds of years. The small spot to the right is the shadow of Jupiter's moon Io.

Going in the other direction, *Mariner 10* left Earth on 3 November 1973, headed inward toward the Sun. In February 1974 it passed Venus, gathering information that confirmed the inhospitable character of that planet. Then, using Venus's gravitational force as propulsion, it charged on toward the innermost planet, Mercury. On 29 March 1974, *Mariner 10* flew past Mercury, providing man a 5000-times closer look at this desolate, crater-pocked, Sun-seared planet than had been possible from Earth. Using the gravitational field of its host planet to alter course, *Mariner 10* flew out in a large elliptical orbit, circled back by Mercury a second time on 21 September 1974, and a third

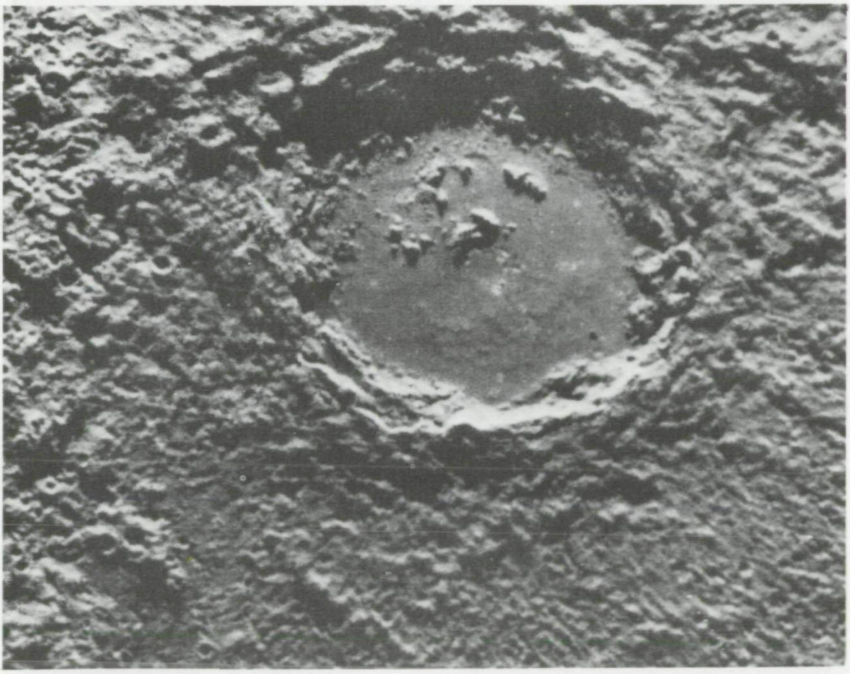
Venus was photographed from 720 000 kilometers by *Mariner 10*.



time on 16 March 1975. The cumulative evidence pictured a planet essentially unchanged since its creation some 4.5 billion years ago, except for heavy bombardment by meteors, with an iron core similar to Earth's and a thin atmosphere composed mostly of helium ringed by a weak magnetic field.

Fascinating as was the information on our fellow-voyagers in the solar system and as important as the long-range scientific import might be, Congress and many government agencies were much more intrigued with the tangible, immediate-return, Earth-oriented program that began operations in 1972. On 23 July *ERTS 1* (Earth Resources Technology Satellite) was launched into polar orbit around the Earth. From that orbit it would cover three quarters of the Earth's land surface every 18 days, at the same time of day (and therefore with the same Sun angle for photography), affording virtually global real-time information on developing events such as crop inventory and health, water storage, air

A large, fresh impact crater on Mercury was photographed by *Mariner 10* from 34 000 kilometers. The crater, 120 kilometers across, looks similar to many on the Moon, but because Mercury has a gravitational field 2.3 times as strong as the Moon's, material ejected at impact is not hurled nearly as far on Mercury.



and water pollution, forest fires and diseases, and recent urban population changes. In addition it depicted the broad-area—and therefore undetectable by ground survey or aircraft reconnaissance—geologic patterns and coastal and oceanic movements. *ERTS 1* also interrogated hundreds of ground sensors monitoring air and water pollution, water temperature and currents, snow depth, etc., and relayed information to central collection centers in near real-time. The response was instantaneous and widespread; foreign governments, states, local governments, universities, and a broad range of industrial concerns became quickly involved in both the exploration of techniques to exploit these new wide-area information sources and in real-time use of the data for pressing governmental and industrial needs. Some 300 national and international research teams pored over the imagery. Accurate estimates were possible for the first time of the total planting and growth status of wheat, barley, corn, and rice crops at various times during the growing season; real-time maps versus ones based on data that would have been collected over a period of years; timber cutting patterns; accurate prediction of snow run-off for water management; accurate, real-time flood damage reports. Mid-term data included indications that the encroachments of the Sahara Desert in Africa could be reversed by controlled grazing on the sparse vegetation in the fringe areas; longer range returns suggested promise in monitoring strip mining and subsequent reclamation and in identification of previously unknown extensions of Earth faults and fractures important to detection of potential earthquake zones and of associated mineral deposits.

Like the experimental communications satellites of the early 1960s, the Earth-resources satellites found an immediate clientele of governmental and commercial customers clamoring for a continuing inflow of data. The pressure made itself felt in Congress; on 22 January 1975, *Landsat 2* (formerly *ERTS 2*) was orbited ahead of schedule to ensure continuation of the data that *ERTS 1* (renamed *Landsat 1*) had provided for two and a half years, and a third satellite was programmed for launch in 1977. This would give confidence to experimental users of the new system that they could securely plan for continued information from the satellite system.

The Earth-resources program had another important meaning. It was a visible sign that the nature and objectives of the space program were undergoing a quiet but dramatic shift. Where the Moon had been the big target during the 1960s and large and expensive programs had been the name of the game, it became increasingly

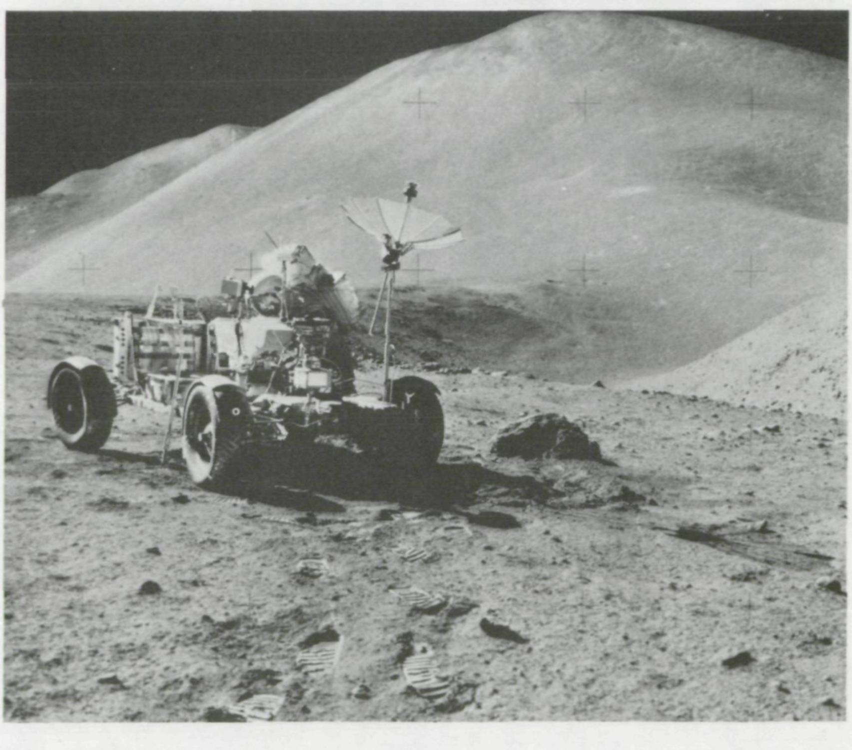
clear to NASA management as the decade ended that the political climate would no longer support that kind of a space program. The key question now was, "What will this project contribute to solving everyday problems of the man-in-the-street?" One by one the 60s-type daydreams of big, away-from-Earth projects were reluctantly put aside —a manned lunar base, a manned landing on Mars, an unmanned "Grand Tour" of several of the planets. When the Space Shuttle finally won approval, it was because of its heavy dedication to studies of our Earth and its convincing economies in operations.

***ERTS* (Earth Resources Technology Satellite) photograph of the Washington-Baltimore area in October 1972. Green, red, and infrared images from the satellite were combined at Goddard Space Flight Center. Healthy crops and trees come out bright red in the infrared. Cities and industrial areas show as green or dark gray; clear water is black or dark blue. Washington is to be seen slightly left of center on the Potomac River; Baltimore is at the top center on Chesapeake Bay.**

Another sign of the times was that NASA was increasingly becoming a service agency. In 1970 NASA for the first time launched more satellites for others—ComSatCorp, NOAA, DoD, foreign governments, etc.—than for itself. Five years before only 2 of 24 launches had been for others. Clearly this trend would continue through the 1970s.

Meanwhile Apollo was running its impressive course. *Apollo 12* (14–24 November 1969) repeated the *Apollo 11* adventure at another site on the Moon, the Ocean of Storms. One attraction of that site was that *Surveyor III* had been squatting there for two and a half years. A pin-point landing put the LM within 183 meters of the Surveyor spacecraft. In addition to deploying scientific instruments and collecting rock samples from the immediate surroundings, Astronauts Conrad and Bean cut off pieces from *Surveyor III,* including the TV camera, for return to Earth and analysis after 30 months of exposure to the lunar environment.

Apollo 15 **Astronaut David R. Scott was photographed by the Lunar Rover, which was parked at the edge of the deep lunar trench Hadley Rille.**



Apollo 13 was launched 11 April 1970, to continue lunar exploration. But 56 hours into the flight, well on the way to the Moon, there was a dull thump back in the Service Module behind the astronauts. An oxygen tank had ruptured. Pressure dropped alarmingly. What was the total damage? Had other systems been affected? How crippled was the spacecraft combination? The backup analysis system on Earth sprang into action. Using the meager data available, crews at contractor plants all over the country simulated, calculated, and reported. The verdict: *Apollo 13* was seriously, perhaps mortally, wounded. There was not air or water or electricity to sustain three men on the shortest possible return path to Earth. But, ground crews and astronauts asked simultaneously, what about the Lunar Module, a self-contained spacecraft unaffected by the disaster? The lunar landing was out of the question anyway; the lifesaving question was how to get three men around the Moon and back to Earth before their life-supporting consumables ran out. Could the LM substitute for the Command Module, supplying propulsion and oxygen and water for an austere return trip? The simulations said "yes." *Apollo 13* was reprogrammed to loop around the Moon and set an emergency course for Earth return. The descent engine for the LM responded nobly; off they went back to Earth. It was a near thing—powered down to the point of minimum heating and communication, limiting activity to the least possible to save oxygen. Again the flexibility and depth of the system came to the rescue; when reentry was safely within the limited capabilities of the crippled Apollo, the "lifeboat" LM was fondly jettisoned along with the wounded Service Module. *Apollo 13* reentered safely.

The next flight was delayed while the causes and fixes for the near-tragedy on *Apollo 13* were sorted out. On 31 January 1971, *Apollo 14* lifted off, the beginning of the scientific exploration of the Moon. The major new system was a transporter—a cart on which to load equipment and bring back rock samples. A major target of the *Apollo 14* mission to Fra Mauro was to climb the walls of the Cone Crater; the attempt failed near the top when the walls turned out to be steeper than anticipated.

Apollo 15 introduced the Moon car, the Lunar Rover. With this electric-powered, four-wheel drive vehicle—developed at Marshall at a cost of $60 million—the astronauts roamed beyond the narrow confines of their landing site and explored the area. Astronauts on this flight covered 28 kilometers of lunar surface, visited a number of craters in the Hadley-Apennines area, and photographed the ghostly ravine

Hadley Rille. Thanks to the lowered exertion level because of the Lunar Rover, exploration time was doubled.

The remaining Apollo missions now had all the equipment planned for lunar exploration. *Apollo 16* landed in the Descartes area of the Moon in April 1972, stayed 71 hours, provided photos and measurements of the lunar properties. *Apollo 17,* launched 7 December 1972, ended the Apollo program with the most productive scientific mission of the lunar exploration program. The site, Taurus-Littrow, had been selected on the basis of previous flights. Objectives were to seek out both oldest and youngest rocks to fill in the geologic history of the Moon. For the first time a trained geologist, Harrison H. Schmitt, was on a crew, adding his professional observations. EVA time was over 22 hours and the Lunar Rover traveled some 35 kilometers.

Apollo was ended. From beginning to end, it had lasted 11½ years, cost $23.5 billion, landed 12 men on the Moon, and produced an unassessable amount of evidence and knowledge. Technologically it had produced hardware systems several orders of magnitude more capable than their predecessors. In various combinations, the components of this technology could be used for a wider variety of explorations than the nation could possibly afford. The luxury of choice was: which of a half dozen possible missions?

Scientific answers were going to be returned over several decades. A Lunar Receiving Laboratory had been constructed in Houston to be the "archive" of the 382 kilograms of physical lunar samples that had been returned from various parts of the Moon by six lunar-landing crews. An unprecedented network of scientists in this country and 54 foreign countries were analyzing the samples with an impressive variety of instruments and the expertise of many scientific disciplines. Gross results had already established that the Moon was a separate entity from Earth, formed at the same time as Earth some 4.5 billion years ago; that it had its own volcanic history; that with no protective atmosphere it had been bombarded by eons of meteors from outer space, which had plowed up the surface and in larger impacts had triggered secondary lava flows from the lunar interior. Refinement of data would go on for decades.

Apollo had proved many other things: the ability of our diversified system of government, industry, and universities to mobilize behind a common national purpose and produce on schedule an immense and diverse system directed to a common purpose. It not only argued that man could do many things in space, whether extended lunar explora-

tion from permanent lunar bases or manned excursions to Mars, but argued that solutions to many of man's major problems on Earth—pollution, food supply, natural disasters such as earthquakes and hurricanes, etc.—could be ameliorated or controlled by the combination of space technology and the large-scale management techniques applied to it.

DRAMA OF SKYLAB

Next in manned spaceflight came Skylab. Trimmed back to one orbital workshop and three astronaut flights, Skylab had had a hectic financial and planning career, the converse of Apollo. The revised plan called for an S-IVB stage of the Saturn V to be outfitted as a two-story orbiting laboratory, one floor being living quarters and the other working room. The major objective of Skylab was to determine whether men could physically withstand extended stays in space and continue to do useful work. Medical data from the Gemini and Apollo flights had not completely answered the question. Since there would be far more room in the 27-meter-long Orbital Workshop than in any previous spacecraft, William C. Schneider, Skylab program director, devised a more extensive experiment schedule than all previous spaceflights combined. Most ambitious in terms of hardware was the Apollo Telescope Mount; five major experiments would cover the entire range of solar physics and make it the most powerful astronomical observatory ever put in orbit. The other major areas of experimentation were Earth-resources observations and medical experiments involving the three-man crew. There were important subcategories of experiments: the electric furnace, for example, would explore possibilities of using the weightless environment to perform industrial processes that were impossible or less effective on 1-g Earth—such as forming perfectly round ball bearings or growing larger crystals, much in demand in the electronics industry.

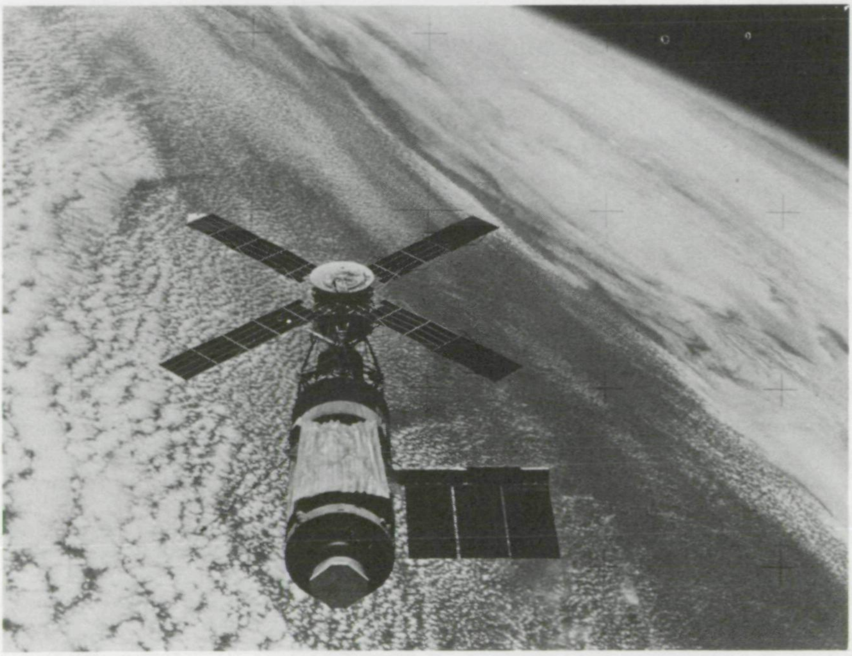
Skylab 1 was launched on 14 May 1973. The giant Saturn V lifted off from Kennedy Space Center to place the unmanned 74 910-kilogram Orbital Workshop in Earth orbit. Within minutes after launch, disquieting news filtered through the telemetry reports from the Saturn V. The large, delicate meteoroid shade on the outside of the Workshop had apparently been torn off by the vibrations of launch. In tearing off it had caused serious damage to the two wings of solar cells that were to supply most of the electric power to the Workshop; one of them had sheared off, the other was snagged in the folded position.

Once the Workshop was in orbit, the news worsened. The loss of the big shade exposed the metal skin of the Workshop to the hot sunshine; internal temperatures soared to 325 K. This heat not only threatened its habitation by astronauts but if prolonged might fog sensitive film and generate poisonous gases.

The launch of the first crew was twice postponed, while the far-flung ground support team worked around the clock for 10 frantic days, trying to improvise fixes that would salvage the $2.6-billion program. With only partial knowledge of the precise degree and nature of the damage, engineers had to work out fixes that met the known problems, yet were versatile enough to cope with unknown ones. There were two major efforts: first, to devise a deployable shade that the astronauts could spread over the metal surface of the Workshop; the other was to devise a versatile tool kit of cutters and snippers to release the undeployed solar wing from whatever prevented it from unfolding.

On 25 May 1973, *Skylab 2,* an Apollo Command and Service

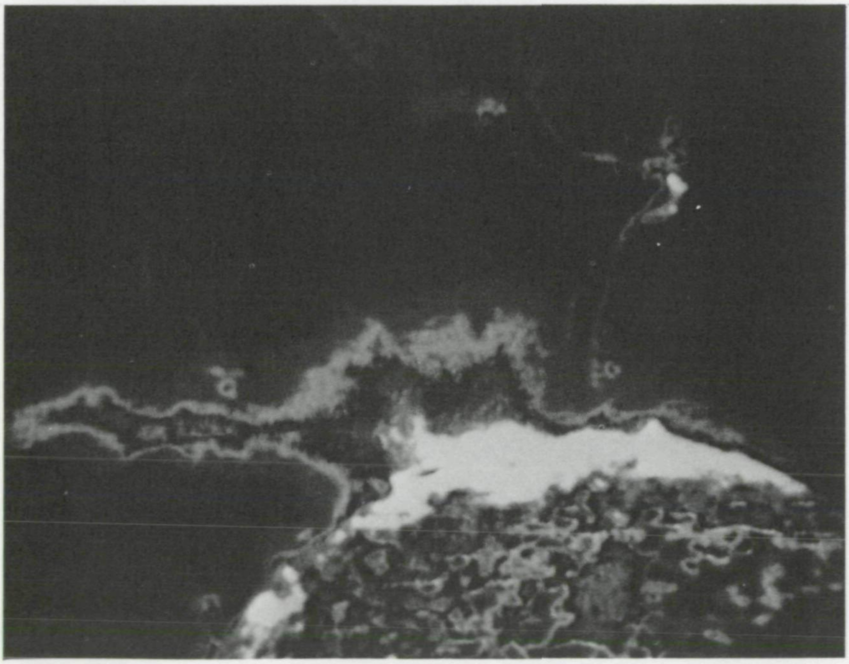
Mission accomplished, the Skylab Orbital Workshop sails serenely above cloud-shrouded Earth in this photo taken by the *Skylab 4* crew as they leave to return to Earth. The mission-saving emergency shroud shows clearly against the dark surface of the vehicle.



Module combination, was lifted into orbit by a Saturn IB to look at the wounded Workshop, try to fix it, and then dock the crew to inhabit it for 28 days. Apollo docked with the workshop on the 25th. The crew entered it the next day and deployed a makeshift parasol through the solar airlock. The effect was immediate; internal temperature of the Workshop began to drop. On 7 June Astronauts Conrad and Kerwin clambered outside the Workshop and after a tense struggle succeeded in cutting the metal straps that ensnared the remaining solar wing; it slowly deployed and electrical power poured into the storage batteries. Human ingenuity and courage had made the Workshop operational again.

The remainder of *Skylab 2* and the follow-on *Skylab 3* and *4* were almost anticlimactic after the dramatic rescue of the Workshop. With only minor problems, the missions ticked off their complicated schedules of experiments. In spite of the initial diversion, *Skylab 2* obtained 80 percent of the solar data planned; 12 of 15 Earth-resources runs were

This color-density rendition of a solar eruption was taken by Skylab's spectroheliograph. One of the ten kinds of telescope in the Apollo Telescope Mount, it covered the wavelengths in the extreme ultraviolet, a part of the spectrum never seen from Earth.



completed; and all of the 16 medical experiments went as planned. Its 28-day mission completed, the *Skylab 2* crew undocked and returned to Earth.

Skylab 3 was launched on 28 July 1973, completed almost 60 days in orbit, and exceeded by one third the solar observations and Earth-resources runs planned. All the medical experiments were performed. *Skylab 4* (launched 16 November 1973) completed an 84-day flight with all experiments performed, as well as the additional observations of the surprise cosmic visitor, comet Kohoutek.

The vast mass of astronomical and Earth-resources data from the Skylab program would take years to analyze. A more immediate result was apparent in the medical data and the industrial experiments. With the corrective exercises available on Skylab, there was no physiological barrier to the length of time man could survive and function in space. Man's biological functions did indeed stabilize after several weeks in zero-g. In the industrial experiments there was strong evidence that the melting and solidification process was promisingly different in weightlessness; single crystals grew five times as large as those producible on Earth. Some high-cost industrial processes apparently had new potential in space.

V

What Next?

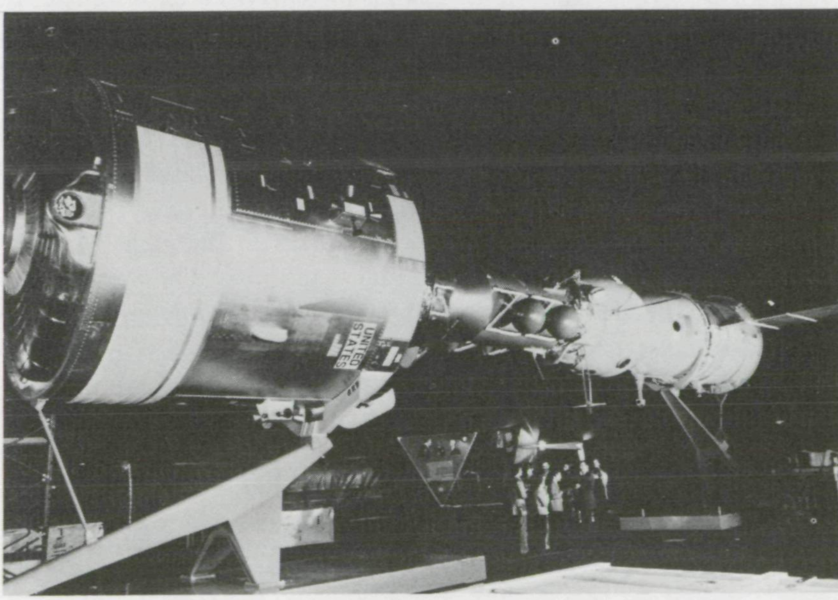
While Skylab was being built, other events significant to the future of space exploration were taking place. The initiatives bore the imprint of Thomas O. Paine, Acting Administrator after Webb's resignation in 1968 and Administrator of NASA from March 1969 until he returned to industry in September 1970. One was a broad approach to increased cooperation in space exploration. As had so many of our international space initiatives in the postwar period, this effort offered separate proposals to the Soviet Union and to Western European countries. The approach to the Soviet Union began in 1968, with suggestions for advanced cooperation, especially in the expensive arena of manned spaceflight. One area of Soviet vulnerability might be that of astronaut/cosmonaut rescue. By now the Soviet Union had lost four cosmonauts in flight, three in one accident, one in another. They had always evidenced a singular concern for cosmonaut safety. Perhaps some joint program could develop a system of international space rescue. The dynamics seemed right; by 1969 the evidence was clear that, whether the Soviet Union had in fact been in a Moon-landing race with the United States, the United States was ahead. Secrecy in space was virtually nonexistent; size of payloads, destinations of missions, performance—all were detectible by tracking systems.

Paine's first offer was for Soviet linkup with the Skylab Orbital Workshop. But the very hardware implied inequity. The Soviets were not interested. Further explorations found lively Soviet interest in a completely new project to develop compatible docking and rescue systems for manned spaceflights. Negotiations proceeded rapidly. Completed by George M. Low, Acting Administrator after Paine's departure, the grand plan for the Apollo-Soyuz Test Project (ASTP) called for a mutual docking and crew exchange mission that could develop the necessary equipment for international rescue and establish such criteria

for future manned systems from both nations. A Soyuz spacecraft would lift off from the Soviet Union and establish itself in orbit. Then an Apollo spacecraft would be launched to rendezvous and dock with the Soviet craft. Using a specially developed docking unit between the two spacecraft, they would adjust pressurization differences of the two spacecraft and spend two days docked together, exchanging crews and conducting experiments. All of this was agreed to and it rapidly became a significant test for the validity of the detente agreements which President Richard M. Nixon had negotiated with the Soviet Union.

An unprecedented detailed cooperation between the two superpowers ensued. A series of joint working groups of Soviet and American specialists met over several years to work out the various hardware details and operational procedures. At the Nixon-Brezhnev summit in 1973, the prospective launch date was narrowed to July 1975. The most concrete example of U.S.–U.S.S.R. cooperation in space was in train and proceeding with good faith on both sides. The mission flew as scheduled on 15 July and smoothly fulfilled all objectives.

ASTP (Apollo-Soyuz Test Project) hardware on view at the Paris Airshow in May 1973. The Apollo Command and Service Modules are on the left, Soyuz on the right; the darker cylinder between them is the newly designed docking module.



The other major initiative of Paine's began on the domestic front and then expanded to the international front. Skylab having been narrowed to the point that it would be a limited answer to the future of manned spaceflight, President Nixon invoked a President's Space Task Group to recommend broad outlines for the next ten years of space exploration. Within this group, chaired by the Vice President, Spiro T. Agnew, Paine won acceptance for the concept of the Space Shuttle. In its original conception, the Space Shuttle would be a rocket-boosted airplane-like structure that would take off from a regular airport runway, fly to orbital speed and altitude, deploy satellites into orbit, repair or retrieve satellites already in orbit, and, using an additional Space Tug stage, lift manned and unmanned payloads throughout the solar system. The big changes from the earlier Space Age would be that the launcher and shuttle would be reusable for up to 100 flights, halving the cost per pound in orbit. But subsidiary changes were only slightly less important: satellites could be designed for orbital rigors, not the additional ones of rocket launch. In a manned mission, the Shuttle could handle up to a seven-man crew in orbit; three of these could be non-pilot scientists who simply went along for the ride to operate their experiments in an unpressurized laboratory carried in the Shuttle cargo bay. Unmanned missions—manned with a crew only—could deliver 29 500 kilograms of assorted satellites into orbit and could land on Earth with a returning payload of 14 500 kilograms.

The report of the Space Task Group to the President was submitted on 15 September 1969. It offered three levels of effort: Option I would feature a lunar-orbital station, an Earth-orbital station, and a lunar surface base in the 1980s; Option II envisioned a Mars manned mission in 1986; Option III included initial development of space station and reusable shuttles but would defer landing on Mars until some time before the end of the century. Eventual peak expenditures on these options were estimated to vary from $10 billion down to $5 billion per year. Study and rework went on for more than two years. Paine left NASA to return to industry; his successor, James C. Fletcher, took office in April 1971 and immediately reviewed the status of the Space Shuttle, particularly for its political salability. He became quickly convinced that the Shuttle as then envisioned was too costly to win approval. Total costs for its development were estimated at $10.5 billion. Fletcher instigated a rigorous restudy and redesign which cut the cost in half, mainly by dropping the plan for unassisted takeoff and

substituting two external, recoverable, reusable solid rockets and an expendable external fuel tank. This proved to be salable; President Nixon approved the development of the Space Shuttle on 5 January 1972.

First Paine and then Fletcher had been trying to get a commitment for a major system in the Shuttle from Western European nations. Their own joint space program had not been an unqualified success. Western European nations had joined to form two international space organizations, ELDO to produce launch vehicles and ESRO to produce spacecraft and collect and interpret results. The technical capability was there, but political liabilities constantly plagued and disrupted—who paid how much of what, which nations got which contracts, etc.? The boosters had three stages, each developed in a different country. The launch record was a gloomy history of one kind of stage failure after another. After years of effort, Western Europe had little to show for its independent space program. A new start was in the air. It was into this restive environment that Paine came to talk about the next generation of the U.S. space program and to hold out promise of some discrete major segment to be developed and produced in Europe—a partnership that would give them a meaningful piece of the action with full pride of useful participation. Europe's response was warm, though it took a while to coalesce. Finally the joint decision was made: Western Europe would jointly build the self-contained Spacelab that would fit in the cargo bay of the Shuttle spacecraft; a pressurized module would provide a shirtsleeve environment for scientists to operate large-scale experiments; an unpressurized scientific instrument pallet would give large telescopes and other instruments direct access to the space environment. The cost—an estimated $370 million. In 1975 Canada joined the international effort on the space shuttle, agreeing to foot the $30-million research and development bill for the Remote Manipulator that will be used by shuttle astronauts to emplace and retrieve satellites in orbit.

The Space Shuttle promised a whole new way of spaceflight—nonpilots in space, multiple payloads that could be placed where they were wanted or picked up out of orbit; new designs of satellites, free from the expensive safeguards against the vibrations and shocks of launch by rocket. Costs of putting a pound of payload in orbit should drop by one half, from $200 to $100. The $5.2-billion program would buy two prototypes for test in 1978 and 1979. Projected flight programs from 1980 to 1991 identified a total of almost a thousand payloads to

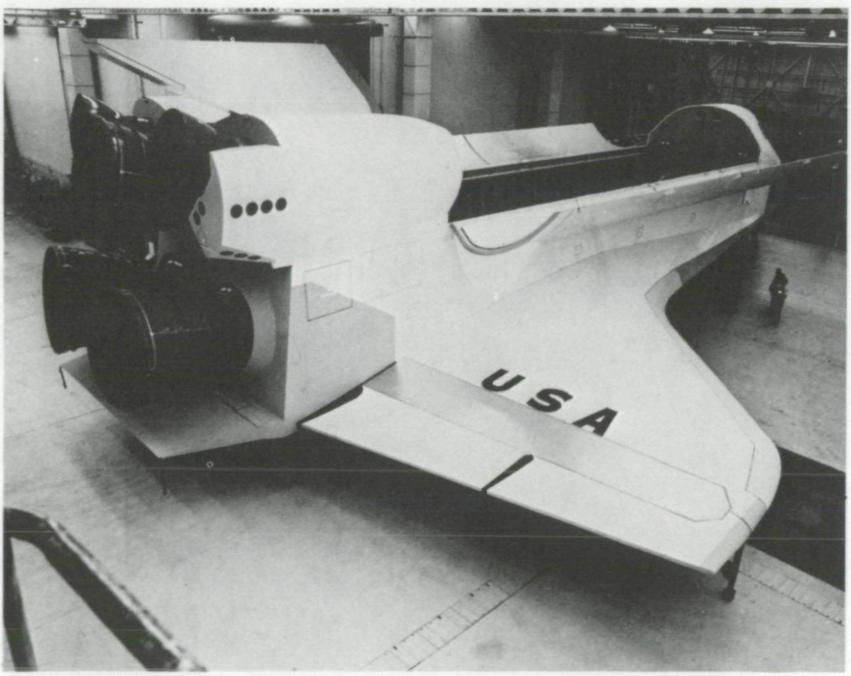
be handled by the Shuttle. True space transportation was in the offing.

In space science, the big program was Viking. A reduced version of the canceled Voyager program, Viking launched two orbiters toward Mars in August and September 1975; after orbiting Mars and refining the landing data, the orbiters would dispatch the first of two sophisticated landers to the surface of Mars, probably in July 1976. Among a number of experiments, the landers would search for evidence of life on that planet.

RETROSPECT

Where has NASA taken us? From the thin ribbon of Earth's atmosphere out to the edge of the solar system in two decades. The Moon, Mars, Venus, Jupiter, Mercury, Saturn being explored. Pulsars, quasars, black holes, all stunning clues to the life cycle of the Universe. Solar flares, the corona, the internal structure of the Sun, all of which have illuminated research to harness fusion energy on Earth. Quiet

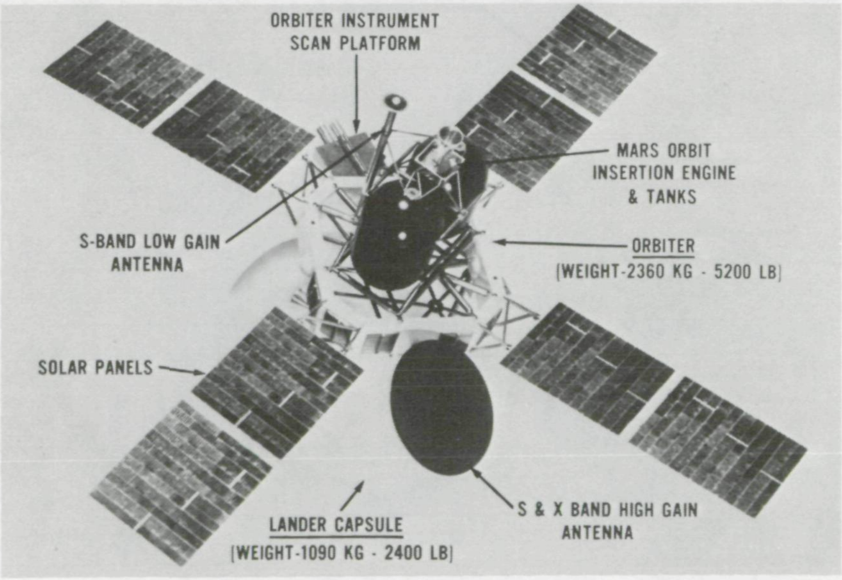
A full-scale mock-up of the Space Shuttle Orbiter. The yawning cargo compartment, 4.9 meters across and 19.7 meters long, can accommodate up to 29 500 kilograms of space cargo and passengers.



aircraft engines, the supercritical wing, economies in fuel consumption in aircraft. Vast improvements in worldwide communications, weather prediction, crop inventories, in knowledge of oceanic ice movements, of fish migrations, of urban development, of broad patterns of geological formations relating to earthquakes and mineral deposits. An expanded industrial and university capability for high-caliber research and development, for ultraprecision, high-performance workmanship. Thousands of new products in the commercial marketplace. These were some of the more immediate returns from the $56- billion investment this nation had made in civil aeronautics and space research through 1975.

Beyond these immediate returns, which are most noteworthy of the less tangible but nonetheless real returns on investment? The international space program, with more than 80 nations involved in mutually beneficial space projects? The joint Soviet-American manned space flight, which has straightened at least momentarily the tortuous path of detente by its irrefutable need for, and achievement of, significant

The two-part Viking spacecraft. The upper octagon with the solar panels attached is the orbiter; the lower circular spacecraft is the lander. After orbiting Mars in mid-summer 1976, the lander was to descend to the Martian surface by parachutes and retrorockets. Its instruments include a pair of color TV cameras, sensing devices to test the soil for the presence of biologic or organic material, atmospheric monitors, and a seismometer.



cooperation? The longer term import of new insights from space sciences on origins of our spacecraft Earth, its mineral and energy resources, the fragility of its thin atmospheric envelope?

And beyond the present and near future, what of the historical lessons? Where else in the twentieth-century history of our nation is more clearly encapsulated our dangerous national trait of international roulette—of a deep-seated complacency that can be penetrated only by extreme challenge: World War I and the too-late founding of NACA; World War II and the belated threefold expansion of NACA; the Cold War and scrambling from behind to NASA and Apollo?

The course of history tells us that new truths, once exposed, defy turning back the clock. The door to aeronautics and space has been opened. It can no more be slammed shut that could the door opened by Gutenberg's printing press or by gunpowder; by Galileo's telescope or by the steam engine; by Pasteur's discovery of germs or by the unleashing of nuclear energy. History impartially muses: who will have the vision and steadfastness of purpose to make the most of this newly opened door?

Finally, what of long-term questions? Will peaceful space competition prove to be a constructive alternative to war on Earth? Will space colonization be the eventual answer to overpopulation and depletion of the fragile planet Earth? Are there super-civilizations in the outer reaches of the Universe who can teach earthlings how to resolve their self-centered conflicts?

At this stage in our excursion into the vastness of space, it is of course too early to venture answers. We are presumptuous even to formulate questions. In all humility, only one finding is certain: our first faltering steps into space have reaped incalculable, unforeseen rewards. Future possibilities are as limitless as man's enterprise chooses to venture.

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The history of aeronautics, and even more so the history of astronautics, is fertile territory for the researcher, simply because it is a big field in which little serious work has been done.

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